

Research Article

Environmental Sustainability of Rice Cultivation in Western Regions of Odisha: A Life Cycle Perspective

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Abstract

Rice, a principal cereal crop often regarded as a staple food, plays a vital role in the agricultural economy of western Odisha. Cultivation of rice needs various forms of material and energy inputs, making it a resource-intensive process, and hence, its environmental consequences are becoming increasingly significant. Consequently, finding the right strategies and solutions to improve sustainability has become essential. The right scientific tools and credible data are required for assessing the sustainability by evaluating the environmental burden associated with rice cultivation. Environmental impact assessment can be performed by various methods, and Life Cycle Assessment (LCA) is one such approach which is widely used. LCA provides intricate details in the cultivation process, which are generally overlooked during most studies. This study evaluates the environmental impacts associated with the rice cultivation process using LCA with a focus on hotspots due to inputs, outputs and emissions. The ReCiPe midpoint methodology has been used to calculate 18 impact indicators. The results were characterized and normalized subsequently for comparison. Results show a Global warming potential (GWP) of 1.34 kg CO₂eq per functional unit. The highest normalized impact was found to be water consumption (3.89E-03), indicating that intensive rice farming has led to high water consumption, while high normalized values of terrestrial (2.86E-03) and marine ecotoxicity (2.83E-03) indicate contamination of water bodies due to excessive fertilizer and chemical use. These impacts pose challenges to environmental sustainability and highlight the need for sustainable rice cultivation practices, including improved water management, balanced nutrient use, and eco-friendly farming techniques, to reduce environmental degradation while maintaining crop productivity.

Keywords

Life Cycle Assessment, Rice Cultivation, Sustainability, Methane Emissions, Global Warming Potential

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1. Introduction

Rice, a synonym for food grain in Odisha, covers a staggering 70% of the state's cultivable land, i.e. around 4.06 million ha and around 90% of the food grain, i.e. 11.93 million tons [1, 2]. Rice cultivation is a resource-intensive process, which is performed with heavy number of inputs which includes pesticide, fertilizers, machineries, land and water which affects the quality of soil, human health and increases environmental burden through release of greenhouse gases (GHGs) [3, 4]. Cultivation of rice serves as a crucial component of regional food security, but with significant burden on ecology through depletion of resources and emissions of harmful gases [5, 6]. Intensive cultivation methods has been linked to soil fertility loss, groundwater depletion, human health hazards and biodiversity decline [7].

Alternative promising farming practices such as system of rice intensification (SRI), organic farming, crop rotation, mulch farming, zero tillage, minimum tillage and integrated pest management are few which are adopted to address these challenges [8]. Organic farming is the most relevant option as it helps in reducing dependence on harmful chemicals but farmers often complain about its reduced yield, high cost and labour-intensive nature. Comparative analyses indicate that traditional and organic rice production systems often demonstrate lower environmental impacts than conventional practices, particularly through reduced reliance on chemical fertilizers and higher renewable energy consumption but heavily varies across cultivation practices adopted in particular region [9, 10]. Numerous studies indicate that the reduced reliance on synthetic nitrogen fertilizers and pesticides in organic systems substantially lowers emissions of Greenhouse gases (CO_2 , NO_x , and SO_x) which are identified as major contributors to global warming and acidification potential [11]. However, the environmental performance of organic systems is not uniformly positive across all impact categories, as trade-offs may emerge in areas such as land occupation and water depletion due to lower yields compared to conventional methods [12]. Before choosing these alternate options and how they perform in comparison to conventional farming it is essential to quantify these harmful emissions, its impact on ecosystem and the underlying cause behind it. These are plenty of methods available among which life cycle assessment (LCA) has emerged as a robust methodological framework which can quantify these environmental burdens throughout the complete production cycle. LCA enables researchers to gauge and compare the ecological performance of diverse agricultural systems [9]. This study employs LCA methodology to evaluate the environmental impacts of rice production systems in the western regions of Odisha, specifically analysing indicators such as global warming potential, energy consumption, and water use and resource efficiency across different stages of rice cultivation [9, 10]. The application of Life Cycle Assessment allows for a comprehensive quantification of emissions, its root cause and answers the underlying cause. It also

provides critical discernments into the comparative advantages of traditional versus modern production systems [10, 13]. By quantifying the total global warming potential LCA helps in identifying key hotspots where interventions can significantly reduce the ecological footprint of rice farming [10, 14]. Despite these nuances, the inherent capacity of LCA to throw light on environmental hotspots within agricultural supply chains remains invaluable for informing sustainable policies and practices [15].

This research therefore, aims to provide a comprehensive life-cycle assessment of intensive rice cultivation practices and environmental impact associated with the inputs specific to western regions of Odisha. Identification of environmental hotspots and mitigation through sustainable alternatives to resource intensive processes. The study focuses standard farming practices adopted by farmers includes inputs specific to that region. Information from this study will aid farmers and policymakers on sustainable agricultural development and policy.

2. Materials and Methods

This section describes the methodology adapted for conducting LCA. The study follows the ISO 14040 and ISO 14044 which provides the guidelines and framework for conducting LCA. Specifically, the four main phases of the LCA include goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation [16, 17]. The LCA framework includes four stages (1) Goal and scope definition, (2) Life cycle inventory, (3) Impact assessment and (4) Interpretation which are discussed in detail in the next section [16].

2.1. Goal and Scope Definition

The current study was carried out as a “cradle to gate” assessment, which include land preparation, seeding, fertilization, irrigation, pesticide application, and harvesting, with particular attention paid to the energy and material inputs at each stage to ensure a robust inventory of environmental flows. The foreground system encompasses direct on-farm activities that have been divided into distinct sub-systems, each representing a crucial phase in the rice cultivation lifecycle, to facilitate a detailed analysis of resource flows and environmental burdens. The background system encompasses the activities involved in producing the agricultural inputs, such as the manufacturing of fertilizers, pesticides and the energy inputs in form of diesel burned in machineries and electricity required for on farm needs. The functional unit for this study is defined as 1 kg of paddy production, which allows for a standardized comparison of environmental impacts across different cultivation practices [11, 18]. Rice straw was not included in the system boundary, and the impact was allocated entirely to the primary

product. Although this could lead to a higher impact as allocation generally distributes the impact based on either the economic value, mass, or energy content of the products and co-products. The system boundary also excludes the distribution

of the rice after it leaves the farm gate, focusing solely on the production phase and transportation of materials itself as shown in Figure 1.

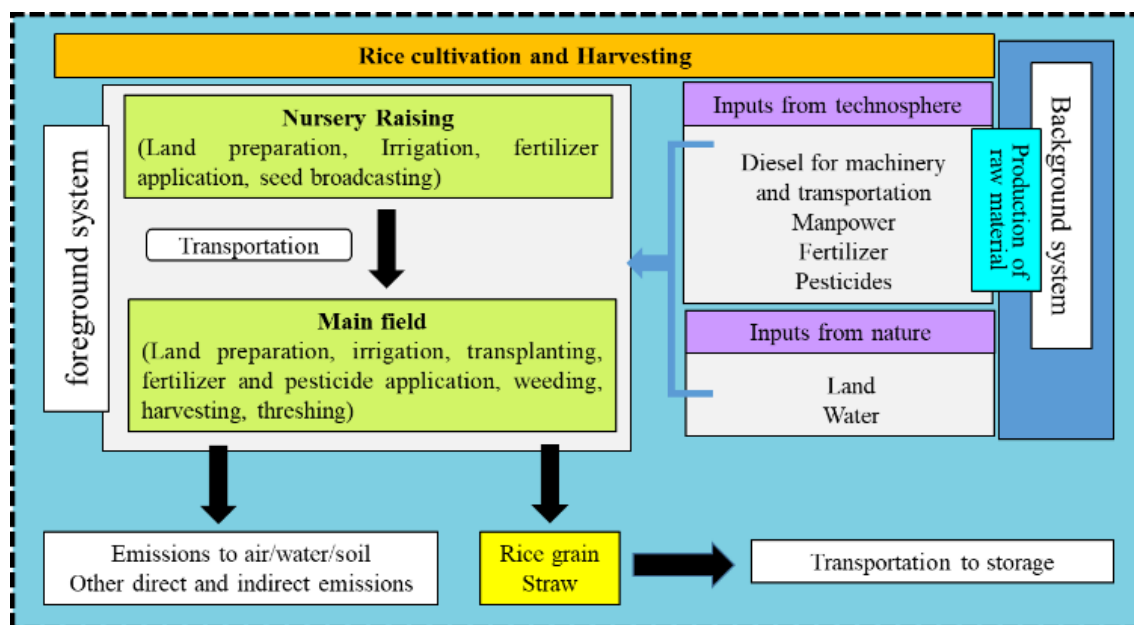


Figure 1. System boundary for the study.

2.2. Life Cycle Inventory

The inventory stage gives details regarding all the inputs and outputs at each stage within the defined system boundary [19]. This section details the compilation of all relevant input and output data used in the LCA model and serves as the basis of analysis [20]. The detailed inventory data is presented in Table 1.

2.2.1. Data Sources

Inventory data for the LCA were meticulously collected from primary and secondary sources, encompassing all material and energy flows associated with the defined system boundaries. It includes inputs like seed, water, land, fertilizer, pesticide, machinery operation, and on-farm emissions [21]. Detailed surveys of farmers from key agricultural blocks of the leading rice producer of the western region, i.e. Bargarh. On-site surveys were conducted in order to gather data relevant data. Secondary data sources for the background system

were taken from LCA literature, Office of district agricultural officer, reports, and the Ecoinvent 3 dataset, which holds good for the Indian context. The production of inputs was also included in the system boundary.

2.2.2. Material Input

Data was collected firsthand of the inputs for paddy cultivation through a questionnaire prepared keeping in mind the inputs considered in the already available database in the software. The inputs are listed in Table 1 with relevant units. The inputs were for the cultivation of 1ha of rice in a continuous flooded field. Data for irrigation were referenced from literature as it is quite difficult to obtain accurate data in the field. Inventory data is divided into inputs from nature, which include land and water. Material inputs from technosphere include seed, fertilizer, pesticides, insecticides, fungicides, herbicides and energy input in form of diesel burned to carry out agricultural operations.

Table 1. Inventory data for paddy cultivation (1ha).

Input	Quantity	Unit	Description	Source
Inputs from nature				

Input	Quantity	Unit	Description	Source
Land	11,000	m ²	Land for nursery and main field	Field area
Irrigation water	11,500	m ³	Total water requirement	[11]
Material Inputs				
Seed	62.5	kg	Input from Ecoinvent 3 database	Field Survey
Urea	180	kg	N (Nitrogen supplement)	Field Survey
Phosphate fertiliser	60	kg	P ₂ O ₅ (Phosphate supplement)	Field Survey
Potassium fertiliser	60	kg	K ₂ O (Potassium supplement)	Field Survey
Manure	2471	kg	Organic nutrient source (NPK)	Field Survey
Zinc monosulfate	19.77	kg	ZnSO ₄ .H ₂ O (micronutrient fertilizer (containing 33% Zinc and 15% Sulphur)	Field Survey
Potassium sulphate	120	kg	K ₂ SO ₄ (K and S source)	Field Survey
Ammonium sulphate	3.216	kg	(NH ₄) ₂ SO ₄ (NPK 21-0-0)	Field Survey
Benzimidazole fungicides	4.94	kg	Fungicide, (for fungal diseases like blast, sheat blight etc.)	Field Survey
Carbaryl	6.6188	kg	Insecticide (for stem borer, leaf hoppers)	Field Survey
Carbofuran	4.13	kg	Insecticide (for broad spectrum insects)	Field Survey, IPM Rice cultivation
Organophosphorus-compound	5.35	kg	Insecticide (for brown plant hoppers)	Field Survey, [11]
Pyrethroid-compound	3.74	kg	Insecticide (for leaf folders, root grubs etc.)	Field Survey, [11]
Fungicide	10.127	kg	Carbendazim 12% + Mancozeb 63% WP (for blast, sheath blight, and leaf spot)	Field Survey
2,4-D	2.685	kg	Herbicide (for broadleaf weed)	Field Survey
Chloroacetanilide herbicides	3.0875	kg	Herbicide (for grassy weeds)	Field Survey
Triazinylsulfonyleurea herbicides	0.1976	kg	Herbicide (for grassy weeds and broad weed leafs)	Field Survey

2.2.3. Energy Input

Energy input plays a vital role in the inventory as the major source is fossil-based fuel, which results in the release of heavy pollutants in prolonged operations. Machineries were used for land preparation, transplantation, weeding, harvesting, threshing and transportation of input material and rice

grain transportation to storage. Energy from diesel burned in these machineries during field operations and transportation as shown in Figure 2 were calculated based on the field capacity and data collected during field operations. The diesel input is converted into mega joules (MJ) with a total calculated value of 13195.8 MJ which a sum of diesel used in agricultural operations.

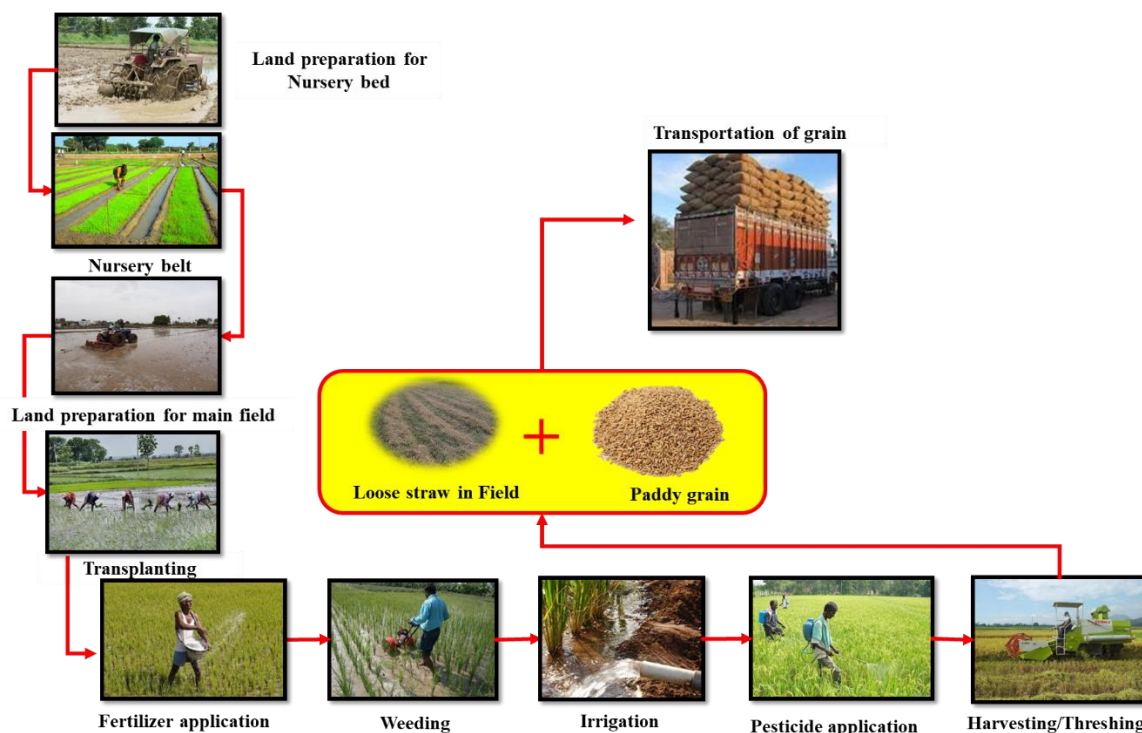


Figure 2. Stages of paddy cultivation taken in the study.

2.2.4. Field Emissions

Emissions from rice fields is the direct cause of intensive water management and intensified further with application of fertilizers. Field emissions includes methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3) and emissions of nitrates and phosphorous to water [22, 23]. Application of urea leads to the emission of carbon dioxide which directly contributes to the

environmental impact of the rice [24]. The emissions were calculated as per the IPCC guidelines [25] and World food LCA database (WFLDB) and secondary data from a similar study in Bangladesh [11]. Direct emission of carbon dioxide from rice field due to application of urea, methane emission due anaerobic decomposition of organic matter, N_2O and NH_3 emission from nitrogen fertilizer. The emission values were calculated and presented in Table 2 and Table 3.

Table 2. Emissions from rice field.

Compartment	Emission	Quantity	Source
Air	Carbon dioxide	258 kg	Calculated value
	Methane	133.28 kg	[11, 26]
	Nitrogen dioxide	5.38 kg	[11, 27]
	Ammonia	31.49 kg	[11, 27]

Table 3. Emission due to phosphorous and water evapotranspiration.

Compartment	Emission	Quantity	Source
Water	Water (evapotranspiration)	5175 kg	[11, 28]
	Water, groundwater	1163.6 m ³	[11, 28]
	Water, river	4654.4 m ³	[11, 28]

Compartment	Emission	Quantity	Source
	Phosphorus, groundwater	0.21573 kg	[11, 28]
	Phosphorus, river	0.061069 kg	[11, 28]

2.3. Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the third phase in the LCA which is based on the LCI results. It involves conversion of raw data into quantifiable environmental damages. The study was performed in the Simapro 9 LCA software with ReCiPe midpoint impact assessment model for calculation of environmental impact. The impact results were categorized into 18 midpoint impact categories with their reference units as shown in the Table 4. The calculated impact were normalized for comparison of impact categories. Normalization is an optional step as per ISO 14040 while characterization is a mandatory step [28].

Table 4. ReCiPe midpoint impact categories.

Impact Category	Impact result	Unit
Global warming potential	1.32E+00	kg CO ₂ eq
Stratospheric ozone depletion	2.38E-07	kg CFC11 eq
Ionizing radiation	8.45E-03	kBq Co-60 eq
Ozone formation, Human health	1.91E-03	kg NO _x eq
Fine particulate matter formation	2.19E-03	kg PM _{2.5} eq
Ozone formation, Terrestrial ecosystems	1.94E-03	kg NO _x eq
Terrestrial acidification	1.34E-02	kg SO ₂ eq
Freshwater eutrophication	7.79E-05	kg P eq
Marine eutrophication	4.09E-05	kg N eq
Terrestrial ecotoxicity	2.97E+00	kg 1,4-DCB
Freshwater ecotoxicity	4.11E-04	kg 1,4-DCB
Marine ecotoxicity	2.92E-03	kg 1,4-DCB
Human carcinogenic toxicity	6.08E-04	kg 1,4-DCB
Human non-carcinogenic toxicity	1.61E-01	kg 1,4-DCB

Impact Category	Impact result	Unit
Land use	2.01E+00	m ² a crop eq
Mineral resource scarcity	1.07E-03	kg Cu eq
Fossil resource scarcity	1.43E-01	kg oil eq
Water consumption	1.04E+00	m ³

3. Results

Impact assessment result based on the allocation method and functional unit is presented in this section with special emphasis on global warming potential and water consumption. The impact indicators were calculated by analyzing the inventory and are listed in Table 4. Impact categories relevant to the current study have been described and compared in the following section.

3.1. Global Warming Potential

Rice production is a major contributor to climate change, primarily through the emission of three key greenhouse gases: methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O) [18]. The GWP for the production of 1 kg of rice was calculated to be 1.3218 kg CO₂ eq. The primary driver of this impact is the cultivation process itself, representing direct field emissions which accounts for 0.8629 kg CO₂ eq (65.29%) of the total GWP. These emissions are largely characterized by the release of 133.28 kg of methane (CH₄) and 258 kg of carbon dioxide (CO₂). Methane is generated by the decomposition of organic matter in anaerobic conditions, which occur when rice fields are flooded. It typically accounts for 30% to 55% of the total GWP of rice production) [18]. CO₂ and N₂O emissions are often linked to the production and application of nitrogen-based chemical fertilizers and the combustion of diesel in farming machinery for field preparation, transplanting, weeding, and harvesting/threshing which adds another 0.2201 kg CO₂eq (16.65%), while the production and application of Urea fertilizer contributes 0.1003 kg CO₂eq (7.59%) as the third largest contributor. The contribution of different inputs to the GWP is shown in the Figure 3.

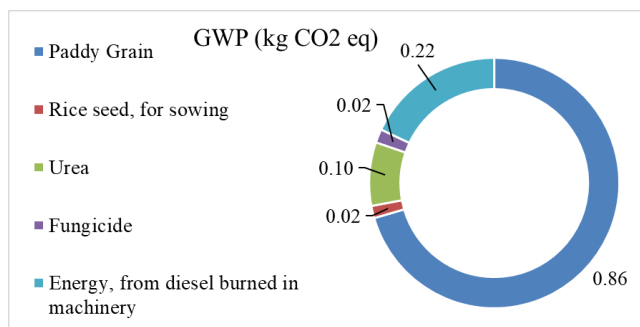


Figure 3. Contribution of inputs to GWP.

3.2. Toxicity and Human Health Impacts

The study identifies a critical environmental hotspot in toxicity categories, specifically linked to micronutrient and pesticide application. Terrestrial ecotoxicity reached a total of 2.97 kg 1,4-DCB, with Zinc monosulfate acting as the overwhelming contributor at 2.4227 kg 1,4-DCB, representing 81.6% of the category. Similar trend extends to human non-carcinogenic toxicity category, where the major contributor was Zits for 0.1468 kg 1,4-DCB out of the total 0.1605 kg 1,4-DCB (89.39%) impact. Other major contributors were found

to be insecticides of Pyrethroid-compounds (14.59%) and Organophosphorus compounds (6.72%), applied for controlling leaf fodder and brown plant hoppers. Highlighting the health risks associated with intensive chemical pest management in Odisha. The human carcinogenic toxicity (6.08×10^{-4} kg 1,4-DCB) and human non-carcinogenic toxicity (1.61×10^{-1} kg 1,4-DCB) categories were contributed majorly by fertilizer (Urea, Phosphate), pesticide (Pyrethroid-compounds) and diesel use.

3.3. Resource Scarcity and Water Footprint

Fossil resource scarcity was calculated at 0.1428 kg oil eq, which is driven primarily by fertilizer, pesticide and diesel inputs. Diesel burned in machinery for on farm operation has the highest contribution (46.62%) followed by Urea (28.36%). Mineral resource scarcity is dominated by phosphate fertilizers, which account for 70.67% of the total impact in this category. Water consumption is a high-impact category with a total of 1.0367 m³ water consumed per kg of rice which shows the water intensive nature of rice cultivation. The majority of this consumption (98.73%) is attributed to the output (grain) as irrigation is directly associated with the outputs of the cultivation process. This shows that irrigation methods should be optimized for reduce this depletion.

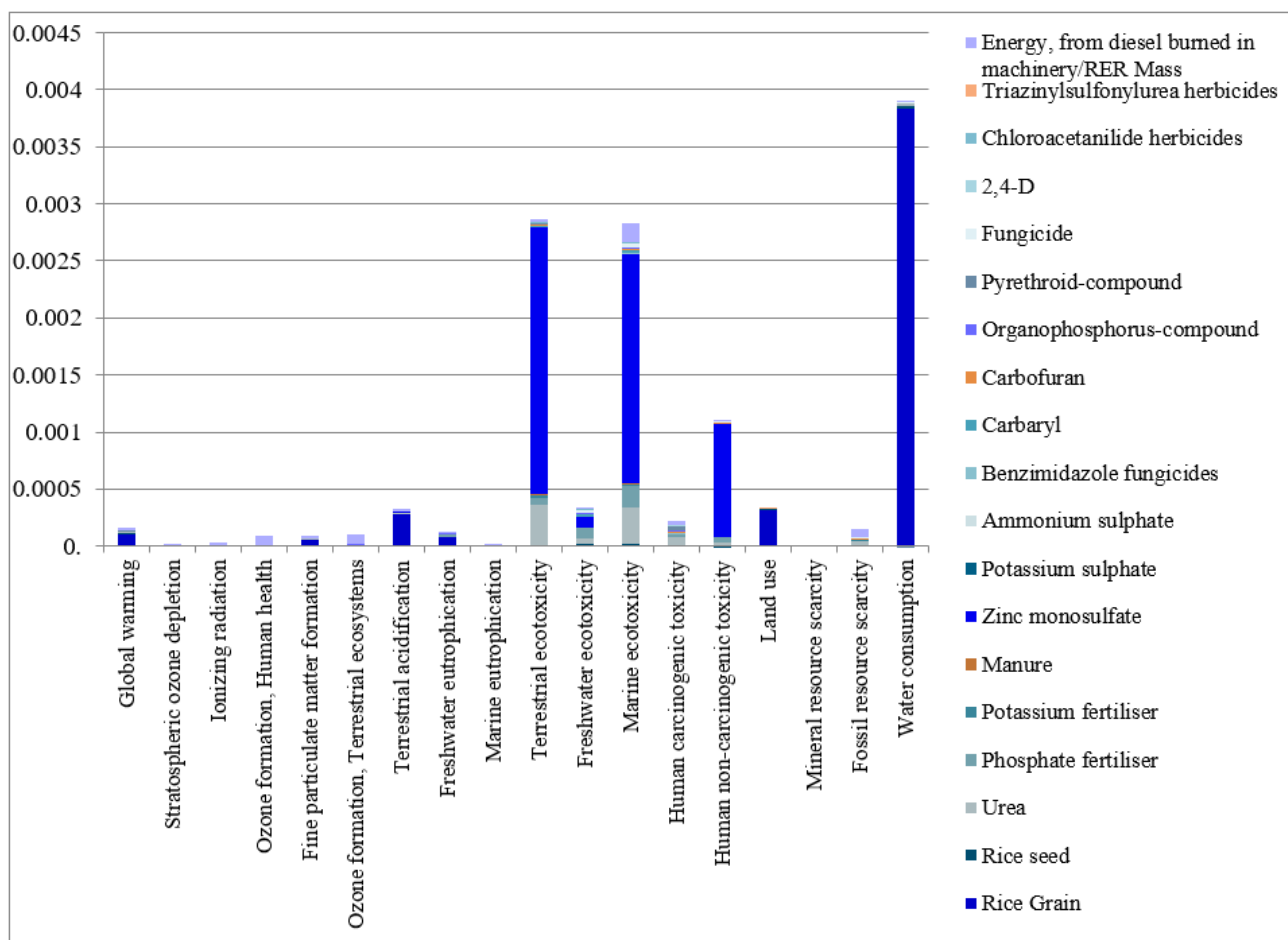


Figure 4. Normalized result.

3.3. Normalization and Comparative Analysis

Normalization is an optional step which is obtained by dividing the characterization result with a normalized factor which represents the total environmental impact of a region over a year and the output is expressed as a fraction of that reference. The results obtained allows for a comparison across different impact categories by converting the output to a common dimensionless value. Figure 4 shows the normalized result plot across different impact categories. The most significant categories were found to be Water consumption (0.00388), Terrestrial ecotoxicity (0.00286) and Marine ecotoxicity (0.002831254). Water consumption is directly associated with the output i.e. rice grain (98.7%) and the remaining 1.3% is contributed by the background processes across all other inputs. The major source of terrestrial and marine ecotoxicity were fertilizer (Urea, Phosphate, Zinc monosulfate) and Energy from diesel burned in machineries. The impact can be reduced by adopting organic amendments and reducing on farm machine operations.

4. Discussion

The GWP for the current study was calculated to be 1.32 kg CO₂ eq per kg of rice, predominantly driven by direct field emissions. Continuously irrigated paddy fields lead to direct field emissions which account for 65.29% of the total GWP. The release of CH₄ due to the anaerobic decomposition of organic matter left in the in flooded fields is a primary contributor and has been reported in similar studies [29]. GWP value has been reported in different studies and tends to vary based on the system boundary, functional unit, input, farming practices and rice processing methods employed after harvesting with typical values ranging from 0.9 to 3.15 kg CO₂-eq per kg [11, 29-32]. This value is lower as compared to various similar studies with similar system boundary, functional unit and input pattern. Beyond field emissions, the diesel use in agricultural machinery (16.65%) and urea (7.59%) are significant secondary drivers of climate impact. These results underscore that while mechanical cultivation and chemical inputs contribute to the carbon footprint, the fundamental method of cultivation specifically water management remains the most critical factor for greenhouse gas mitigation.

A LCA on rice cultivation in Bangladesh reported the GWP to be 3.15 kg CO₂eq which was due to primarily due to methane emission from field while a similar study reported a contribution of 2.9 kg CO₂eq due to non-mechanized irrigation practices [11, 33].

Normalization results indicate that water consumption as the most significant environmental impact category (3.89E-03). Irrigation input was found to be the most impactful category and had the highest contribution in 15 out of 18 selected categories due to direct emission of methane released due to methanogenesis in the irrigated field. Impact was further escalated causing

indirect emissions cause by water conveyance [29]. Hence, water management system plays a vital role. The current study also shows the water intensive nature of the rice cultivation with 1.04 m³ of water per kg of rice, with 98.73% of this consumption attributed directly to irrigation needs. This high-water footprint is a direct consequence of the traditional flooding methods currently employed by farmers in Western Odisha. Such intensive water use poses a severe threat to regional groundwater levels. Transitioning from continuous flooding to more efficient systems, such as drip or sprinkler irrigation, could significantly reduce this depletion while maintaining productivity. Non-continuous flooding and straw management practice can help in reducing water depletion as well as emissions of CH₄ [30].

A study in Malaysia reported relatively lower values of GWP (0.457 kg CO₂-eq), water use (0.098 m³) and fossil fuel depletion (0.084 kg oil-q) for conventional rice while for organic rice these values were 0.140 kg CO₂-eq, 0.029 m³ and 0.022 kg oil-eq respectively. Cultivation phase was found to be the main contributor due to the application and production of fertilizer and pesticides. The current study also reported these values with a higher impact revealing that these values [34].

The study identifies a critical hotspot in terrestrial and marine ecotoxicity, largely linked to the application of micronutrients and pesticides. Zinc monosulfate emerged as an overwhelming contributor, representing 81.6% of the terrestrial ecotoxicity category. Furthermore, the use of Pyrethroid and Organophosphorus compounds for pest control contributes significantly to human non-carcinogenic toxicity. These findings highlight the environmental and health risks associated with intensive chemical management in the region, where excessive fertilizer and pesticide use leads to the contamination of water bodies. The effect of agrochemical on human health, food, and environment Surface water is also contaminated with use of pesticide which effect both aquatic and marine life [35].

The reliance on fossil-based fuels for machinery operations and the production of synthetic inputs drives resource scarcity [36]. Diesel burned during field operations is the primary driver of fossil resource scarcity (46.62%), followed by Urea (28.36%). Additionally, phosphate fertilizers dominate the mineral resource scarcity category, accounting for over 70% of its impact. Reducing these impacts will require a shift toward greener energy options and more balanced nutrient management to decrease the dependence on non-renewable resources. Organic farming have reportedly shown better environmental performance with lower GWP, fossil resource scarcity, human health impact and in many more categories which is proven to be a better alternative [35].

5. Conclusion

The environmental impact assessment of rice cultivation in western region of Odisha shows that inputs like fertilizer, pesticides and fossil resources has a significant contribution across different impact categories. LCA is a tool which can

guide to understand these impacts and identify the critical point and thus sustainable solutions can be explored. The choice and quantity of inputs greatly affect the output and thus should be regulated properly. Greener options can lead to reduction of these impacts which can be incorporated in different stages of rice cultivation. Organic farming is a potential alternative and can reduce the chemical released by the use of synthetic fertilizers but could reduce the yield and hence the choice of chemicals compounds used in these inputs can be regulated to reduce this impact. Irrigation has been found to be a major hotspot as the method adopted by the farmers is still the flooding of fields. This could be reduced by adopting more advance drip and sprinkler irrigation systems. This study evaluated the impact of rice cultivation through a life cycle perspective in an effort to identify the significant contributors and study the emission on a system level. The results from this study could be communicated to the farmers providing an opportunity to change their behavior and change the inputs accordingly. Communicating of this result to farmers is itself an overwhelming task and could be a topic of future research. Life cycle modelling is a data driven process and output results depends on the quality of the life cycle inventory and hence should be evaluated in detailed manner. Most studies include data non-relevant to the region and hence the results are non-reliable and inaccurate. The current study also relies on many literature data and hence can be further improved in future studies. As the first LCA conducted specifically for rice cultivation in Western Odisha, this study provides a vital baseline using 18 impact categories. Future research should strive for more region-specific primary data to enhance accuracy. This study focused solely on rice grain, excluding rice straw from the system boundary. Including co-products in future analyses might redistribute and lower the impact allocated to the primary grain employing suitable allocation. The study has provided qualitative data which can be further investigated in future studies.

Abbreviations

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
GWP	Global Warming Potential
GHGs	Green House Gases
SRI	System of Rice Intensification

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Author Contributions

Suraj Kumar Samal: Conceptualization, Investigation, Data curation, Methodology, Writing – original draft

Sudhansu Sekhar Sahoo: Supervision, Resources, Validation

Pritikrishna Majhi: Data curation, Writing – review & editing, Visualization

Mahendra Kumar Mohanty: Supervision, Resources, Validation

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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Mahendra Kumar Mohanty is an Emeritus professor in the Renewable Energy Division at the College of Agricultural Engineering and Technology, OUAT, Bhubaneswar. With 29 years of professional experience, his career spans roles from Junior Scientist to Professor. An alumnus of IIT Kharagpur (M.Tech) and IIT Delhi (Ph.D.), he has been recognized as

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Research Field

Suraj Kumar Samal: Farm machinery, Ergonomics, Renewable energy, Life cycle analysis, Biofuel from lignocellulosic biomass

Sudhansu Sekhar Sahoo: Fluid and Thermal Engineering, Energy Systems, Renewable Energy, Solar Thermal, Energy Management, Waste Management

Pritikrishna Majhi: Microbiology, Bioremediation, Microalgae, Biofuel, Conservation Biology

Mahendra Kumar Mohanty: Renewable energy, Farm machinery and power, Biofuel production, Waste management, Solar photovoltaic