SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Life Cycle Assessment of Rice Production in Muda Granary Area, Kedah Malaysia

Nurfarhain Mohamed Rusli[1], Zainura Zainon Noor[2,*], Shazwin Mat Taib[1]

[1] Department of Environmental Engineering, Fakulti Kejuruteraan Awam, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Centre of Environmental Sustainable and Water Security, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Article history:
Received 5 July 2023
Received in revised form 27 November 2023
Accepted 8 December 2023
Available online 19 December 2023

Keywords:
Life Cycle Assessment; Muda Granary; rice; sensitivity analysis

ABSTRACT

Rice is a crucial part of everyday Malaysian diet. The demand for rice in year 2030 is projected to be around 533 million ton of milled rice and known to be a high-water consuming crop. It is mainly cultivated in Kedah of Malaysia under irrigated conditions. It is responsible for the environmental degradation due to inefficient use of factors of production, low yield as well as being grown under ponded conditions. Therefore, this study was designed to assess the environmental impacts of rice production in Muda Granary Area in Kedah using life cycle assessment (LCA) approach. Data was collected from Muda Agricultural Development Authority (MADA) and one of rice milling's factory in order to identify the environmental impacts with different phase of production. It was observed that different production practices and different levels of input consumption contributed to the different environmental impacts. The LCA considered the entire system required to produce 1 kg of rice. All impact assessment categories were considered and the sensitivity analysis was performed to test the cut-off criteria set for the chemical input by increasing the solvent input to 15% and including trace amounts of heavy metals. Results from ReCiPe impact assessment methods concur that the top impact categories are rice plantation compared to rice milling and land preparation phase. These include climate change, eutrophication, ecotoxicology, and water depletion. As a result, it is concluded that the fertilizers used were excessive and should be examined further. The study concludes that the greatest impacts of rice production in a Muda Granary area in Kedah are from rice planting phase. It is learnt that the quantity of fertilizers used were excessive and must be looked into. The results of the study will likely provide a good basis for future LCA research on paddy cultivation, especially in terms of nutrient management.

1. Introduction

Rice is major crops and also a crucial part of Malaysians diet. Reports [1], stated that 1.66 million metric tons of rice has been produced in Malaysia while statistics shows that 36.3 million metric was worldwide production. This shows that the country's production of rice is only 0.4% of the total world rice production. Up until today, Malaysia only requires 80% of the produce while exporting the rest

* *Corresponding author.*
E-mail address: zainurazn@utm.my

https://doi.org/10.37934/araset.35.2.6983

to neighbouring countries such as Vietnam and Thailand. Consequently, Malaysian citizen needs 82.3 kilograms of rice annually and 1 hectare of paddy field can produce such average 3.7 metric tons (MT) of rice [2]. Rice is one of the major crops feeding the world population and is most important in South Asia and Africa [3]. Large irrigation projects are often constructed to meet the water demand in rice production. As a result, rice is one of the largest water consumers in the world.

The statistic shows that around 250 million hectares, about 17% of total agricultural land worldwide is irrigated today, this amount is almost 5 times more than the early of 20th century and hence it is about total 40 % of paddy crops is contributed worldwide [4]. Irrigation plays an important role in helping to boost the agricultural yields, at the same time it also stabilizes the food prices. In year 2009, total 57% of paddy is harvested from irrigated area, 28% are from rain fed low land area and 11% from highland while 4% from others area. Studies shows that irrigated paddy was contributing about 75% of overall paddy production [4]. During the irrigation period, the amount of water which used to apply on crops is usually more than the amount that the field need. Hence, this may cause a large amount of surface water runoff, seepage and percolation at around 50-80 % of total amount of water input into the paddy field [5]. Thus, the water crisis that we are having today is not because of limited water which cannot satisfy our demands in agriculture but due to poor water management. If water continues to be heavily subsidized or be offered free, water consumption among Malaysians is not expected to be reduced significantly anytime soon [6].

Globally, climate change has compelled governments to pursue sustainable farming practices as a response to the threat of food security it poses [7]. Agriculture contributes a significant amount to greenhouse gas (GHG) emissions; it uses almost 35% of the total land area and is responsible for 13.5% of the emission of GHGs [8]. It is estimated that rice contributes 55% of the total GHG emissions from the agriculture sector [9]. Due to its flooded, anaerobic conditions [10], rice is also a highly water-intense crop and therefore emits significant amounts of CH_4 besides other GHG emissions measured at the field level [11]. It also able to assess the environmental impact such as to quantify the total amount of polluted water related the use of pesticides, fertilizer and weeds killer in paddy plantation (grey water). Major environmental concerns from rice plantation include emission of greenhouse gases, eutrophication, and acidification [12,13]. There have been numerous LCA studies on rice production conducted by countries such as Thailand, China and Japan. The assessment criteria in these studies often place a strong emphasis greenhouse gas emission and carbon foot-printing [14]. As popular exporters of rice, countries like Thailand and China have been very active in studying impact from rice production to ensure measures are in place to avoid harm to the local environment. Meanwhile countries like Japan, whose national environmental policy places a strong emphasis on curbing greenhouse gases, it is expected that much of the assessment would be focused on methane and carbon dioxide emitted at different stages of the life cycle. Studies by [15] was among the LCA studies conducted on rice production in Japan that aimed at identifying best practices that would curb greenhouse gas emissions.

Life cycle assessment (LCA) is an appropriate methodology designed to study all environmental impacts connected to an entire production system [13]. All impacts are related to one common unit and are summarized into environmental effects or aggregated into a comprehensive environmental index. Such an index allows the ranking of different products or production alternatives according to their overall environ- mental performance. LCA has been incorporated into the ISO 14046 environmental management system, serving as an important tool for environmental management. The growing concern about sustainable food production and consumption has prompted much more research on the LCA of agricultural production activities [4,7,13,15-17,19]. In this study, we describe the application of LCA to investigate environmental impacts of the rice production system in the Muda Granary area and offer several suggestions to minimize negative impacts on the environment.

For such examination, LCA is often implemented to check the impacts of farming on environment (global warming, eutrophication, possible damage to living things) [14,20]. Thus, this LCA study fills the research gap by describing and quantifying the environmental impacts of paddy production on a selected paddy field in Muda, Kedah, Malaysia by identifying and quantifying pesticide use and fertilizer use in paddy cultivation. The production of paddy and rice is influenced by a variety of factors including seed quality and variety, crop management, agronomic practices, pest and disease management, and infrastructure facilities. Consequently, it is of utmost importance to develop rice production practices which utilize user-friendly and environmentally friendly modern technologies to produce higher yields while limiting natural resource use. Malaysia is one of the leading producers and exporters of rice in the world. But several factors such as stagnant yield, nitrogen use efficiency and nitrogen surplus significantly contribute to environmental degradation [21]. Besides, rice cultivation in Malaysia is contributing towards the water scarcity as well as towards the land degradation in terms of water stress index in that area [22]. Therefore, this study aims to investigate the potential environmental impacts of rice production systems in Muda Granary area and figure out ways to potentially reduce is negative environmental impacts.

For that reason, this particular LCA study strives to fill in such research gap by providing a genuine attempt to exhaustively assess the impact of pesticides and fertilizers on the environment during rice production. Therefore, this study aims to specifically identify and quantify the environmental impacts of paddy production from land preparation until rice milling stage. To achieve the above-mentioned objective, data such as information on the seeds used, fertilizer and pesticide type as well as quantities and energy information for all agriculture equipment used will be collected and used to calculate the environmental impact of rice cultivation using LCA. Then, the analysis of assessment in rice milling also conducted to compared the result. Once the LCA is complete, information obtained from the impact assessment phase will then be extrapolated to regional level to estimate the impact from paddy cultivation to the regional environment.

2. Methodology

Rice production in Malaysia is classified into 3 processes. In this study, the boundary of a farm begins with land preparation, not with the transportation of raw materials there. As indicated by this system boundary, this study is gate-to-gate since the processes involved in this study are related to rice field (known as gate). In this study, gate-to-gate provides a big picture of the system boundary. Therefore, to create a big system boundary, other smaller systems must connect to it. The small system boundary includes land preparation, rice cultivation, and rice processing at the mill. The process after the final production of rice to consumer is not included in this boundary because only gate-to-gate process is taken into consideration. Figure 1 shows the system boundary for this study. Basically, this boundary represents the current practice of conventional rice production in Malaysia.

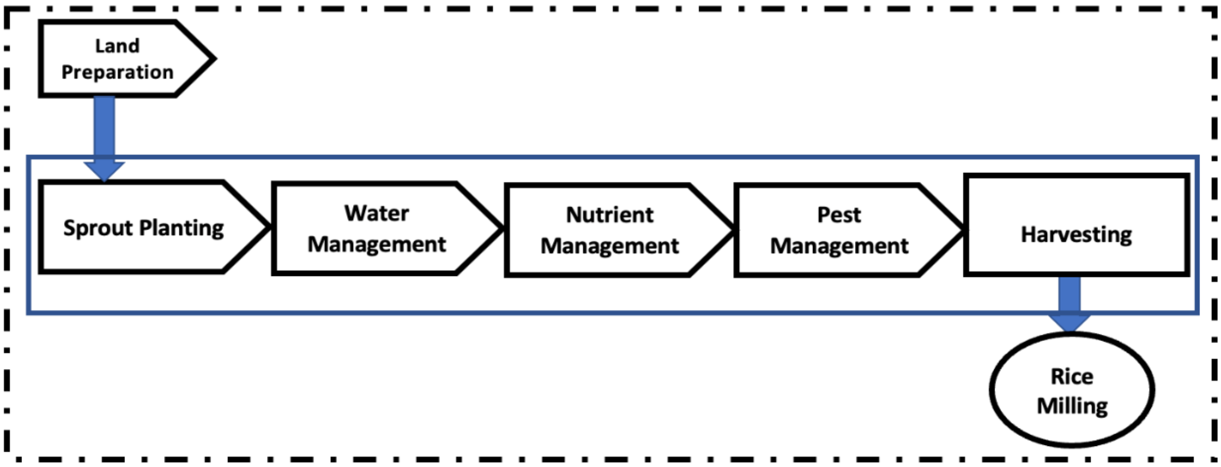

Fig. 1. System boundary of the study

2.1 Study Area

The largest coastal alluvial plain for rice cultivation is the Kedah-Perlis plain [23] where the largest of the eight granaries and the Muda Agriculture Development Authority irrigation scheme are located. The Muda Irrigation Scheme is Malaysia's largest rice granary. Located in Kedah and Perlis in the northern part of Peninsular Malaysia, it covers 191,853 ha of paddy land. Figure 2 illustrates the area of paddy in Muda Irrigation Scheme in Kedah, which has jurisdiction over the two biggest rice granaries in the north-western and north eastern plains of Peninsular Malaysia [23]. This area has been a key area in the paddy sector since it includes the largest granary in Peninsular Malaysia which covered from region I to IV (Figure 2). It produces 940,561 tons of rice, a staggering 41.5% of the total rice production among the eight granary areas in Peninsular Malaysia. Interviews were conducted with small-scale paddy farmers in the main paddy granaries under double cropping in Kedah State.

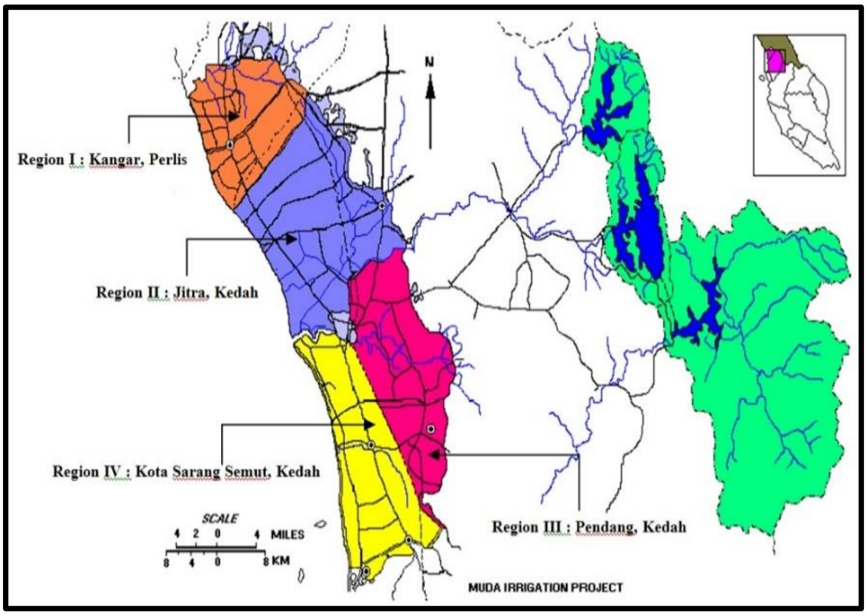

Fig. 2. Layout plan of Muda Area

2.2 Data Collection

In the study, data was collected from MADA (Muda Agricultural Development Authority), located in Alor Setar, Kedah, Malaysia, as well as from one of the companies for the rice milling process based in Pendang, Kedah. Raw rice was selected from the rice mill for the study. To establish the type of water used in producing rice, volume of water used and to reduce the consumption of fresh water, several data were needed in order to perform water footprint of rice production. To gain the data input and output in rice plantation, a site visit and interview will do at several plantation and mill in Kedah, Malaysia.

2.3 Life Cycle Assessment of Rice Production

According to the International Organization for Standardization (ISO) and the Society for Environmental Toxicology and Chemistry (SETAC) [24], the LCA methodology consists of four interrelated stages: goal and scope definition, inventory analysis, impact assessment, and improvement assessment. LCA is a method for quantifying and evaluating a product's inputs, outputs, and potential environmental impacts over its life cycle based on ISO 14040 [25].

2.3.1 Goal and scope definition

The goal of this study is to assess the environmental impact of rice production system at a chosen paddy field in Kedah focusing on paddy cultivation stages as the system started from land preparation to harvesting and finally at milling stage. Special attention was given to identify the water inventory of these activities as well as the environmental impacts of pesticides, fertilizers and other chemicals involved during the nutrition management stage in the cultivation process. Based on the ISO standards, functional unit (FU) is the quantified performance of a production system to be used as a reference unit [26]. The functional unit of this study is defined as 1 kg of rice. The rice production system in the study was divided into three subsystems: land preparation, rice plantation and rice milling. This study was carried out from a cradle-to-farm gate perspective. The process after the final production of rice to consumer is not included in this boundary because only gate-to-gate process is taken into consideration.

2.3.2 Inventory analysis

Data were collected on three process systems: land preparation phase, paddy planting phase, and rice milling phase. We obtained data for the land preparation and paddy planting phases from MADA located in Kedah. Integrated into the LCA software package is Ecoinvent 3.3, which contains inventory data for other processes and auxiliary information for the system. The inventory was further separated into five inputs categories namely:

i. Raw material
ii. Transport
iii. Utility
iv. Chemical
v. Waste

Several measurements of direct energy consumption and ancillary materials were obtained from the field. Farmers and MADA officer who owned the agricultural machineries will be interviewed to obtain the energy data. As rice species and soil use in different farm might result in different usage of fertilizer, pesticides and weeds killer, hence data which going to be used in the modelling is the data which will be collected through personal communications and questionnaires from rice farms and MADA. We used primary data in this research, which were obtained through technical visits to production fields (data related to soil preparation, sowing, organic compound or mineral fertilizer inputs, and harvesting); technical visits to the processing plants and data from interviews carried out with supervisors of the industrial and agricultural processes. Data were collected by application of the questionnaire referring to the years of 2015 rice crop farming in Muda Rice Granary, following the procedures on ISO standards 14046:2014. Secondary data was also used to obtain information on electricity in rice processing at mill for each process involved in the stage. Additional secondary data were taken from the literature (such as electricity consumption during rice processing at mills for each stage) and databases [27]. Once all inputs and outputs had been compiled, the life cycle impact assessment (LCIA) stage, the most common impact categories; ecotoxicity, eutrophication, climate change and water depletion. The analysis was performed using ReCiPe baseline method using GaBi software.

2.3.3 Interpreting results and identify environmental impacts

The LCA studies will be using GaBi software to assess potential environmental impacts of rice plantation system in Muda Rice Granary. At the same time, comparison for 3 processes will be made by studying the impacts from the land preparation process until rice milling process. By the end of the study, the total life cycle impacts of MUDA area of paddy harvested area will be obtained from the GaBi analysis. Countermeasures to optimize the reduction of the potential impacts should be proposed by the end of the study after interpret the results and identified the environmental impacts.

3. Results

Life cycle impact assessment was conducted in order to translate the results of inventory analysis (LCI) into environmental impacts. This provides enough information to guide decisions regarding the consequences of these inputs and emissions [28]. In LCIA, there are essentially two techniques. They are problem oriented (mid-points) and damage oriented (end-points). Flows are grouped into environmental themes to which they contribute in problem-oriented (mid-point) methods, which include a wide range of environmental effect categories. This also streamlines the complexity of hundreds of flows into a few key environmental regions. In this study, the problem-oriented ReCiPe mid-point strategy was chosen based on the facts.

3.1 Environmental Impacts of Rice Production in Muda Granary Area

In the LCA study, a series of environmental impact categories were adopted based on the environmental impact packages included in the ReCiPe life cycle assessment methodology. These impacts were generated based on the input and output included in the life cycle inventories. The details of the input/output were presented in the life cycle inventory sections. Gate-to-gate is a concept that was applied to the boundary of the life cycle assessment study, in which the assessment process was considered from the land preparation phase through to the rice milling process. Auxiliary materials such as water, electricity, and fuel were also included. These three processes were assessed to identify the environmental performance of rice production in Malaysia. Insufficient data from rice milling allows us to exclude the environmental impact of rice distribution to consumers. The developed scenarios are discussed in the following section.

Land preparation starts in May and August after the harvest. Main season refers to period of rice planting without depending on the irrigation system, mainly in August to February, whereas off-season is a period when rice planting is normally dependent on the irrigation system, between May to July. Pesticides were applied multiple times during the rice cultivation process. During the land preparation phase, the first application of pesticides was performed after the second ploughing and harrowing process. Considering the rice plantation process, pesticides (chlorophacinone or warfarin) were applied to reduce the rat population and to prevent the presence of golden apple snails in the rice field. Herbicide application was performed twice in the land preparation phase. The herbicides used were paraquat, glyphosate, and glufosinate. In the cultivation phase, pesticides and herbicides were applied approximately eight times using a rotor sprayer. The pesticides and herbicides used in conventional rice fields included propanil, quinclorac, sulfonylurea, fipronil, cartap, niclosamide, and formaldehyde.

The chemical fertilizers were applied four times in conventional rice cultivation. The fertilizer used included nitro- gen (N) from ammonium sulphate, phosphorus (P) from rock phosphate, potassium (K) from potassium chloride, and urea from animal manure. The amount of fertilizer applied was 350 kg/ha for NPK and 140 kg/ha for urea. However, these primary data could not be immediately entered into the GaBi software without a series of adjustments. As a result, the raw data had to be transformed to obtain the mass chemical inputs as well as suitable energy inputs can be keyed into GaBi. The alteration of these raw data was made through secondary sources such as scientific journals, material safety data sheet (MSDS) and phone calls to MADA. Inputs and outputs of pesticides and fertilizers were only relevant at the sprout planting stage. Obtaining the most credible data about pesticide input in this study was by far the step that required the most effort. A major reason behind this is that the pesticide manufacturing industry is heavily guarded by its players, and information about its ingredients is scant.

The local, well-known brand JATI rice is one of the products in Malaysia. It is one of the nation's leading rice millers and wholesalers focusing on rice business. The business covers an extensive scale of activities ranging from processing, packaging to producing more than 20 different varieties of rice product under the flagship brand JATI. Due to business confidentiality concern, some of the data are not available. However, data concerning mill operations was obtained from interview with rice mill persons in charge who have shown a video of rice processing while explaining the parts involved with the use of fresh water. The business covers an extensive scale of activities ranging from milling, processing, packaging to distribution of various rice and rice products under flagship brand JATI. The environmental impacts of rice production systems rice production in Muda Granary area shown in Table 1.

Table 1
Summary result for three process of rice production in Muda Granary Area

Impact Category	Unit	Land Preparation	Rice Planting	Rice Milling	Total
Climate Change	kg CO_2 eq.	0.1421	3.0504	0.2380	3.4305
Freshwater Ecotoxicity	kg 1,4 DB eq.	0.0067	3.6746	0.0037	3.6850
Freshwater Eutrophication	kg P eq.	0.0000	0.0538	0.0004	0.0542
Marine Ecotoxicity	kg 1,4-DB eq.	0.0041	3.0232	0.0032	3.0304
Marine Eutrophication	kg N eq.	0.0002	0.0304	0.0001	0.0307
Water Depletion	m^3	0.3781	264.6668	0.3917	265.4366

In this study, the environmental hotspot in rice production was assessed using the gate-to-gate approach. According to the results, the climate change impact of 1 kg rice production in the area is 3.4305 kg CO_2. Rice planting was identified as the major source of all environmental impacts in the assessment of rice production. According to the study on the rice planting section, the main impact is caused by fertilizers, which cause climate change, eutrophication, and water depletion. In contrast, pesticides and herbicides in the chemical category significantly impacted ecotoxicity. Rice cultivation produces ammonium ions, N total, CO_2 and CH_4, all of which contribute to climate change, eutrophication of freshwater, and water depletion. In the waste category which referred to methane emissions, major contributors were identified as ammonium ions, N total, CO_2, and CH_4.

Based on the results obtained from this study (Table 1), improvements can be made in relation to fertilizer and pesticide application, water consumption and diesel burned in machinery to reduce emissions from rice fields. Fertilizer and pesticide applications should be decreased, and they should not exceed the recommended amount advised by the Ministry of Agriculture and rice authorities. The extensive use of fertilizers has been identified as a major contribution to the potential for global warming [2,19,24,29-31]. Pesticide use should be replaced with a more environmentally friendly method like integrated pest management (IPM). The life cycle inventory analysis shows that the microbial degradation process of the fertilizers results in a significant release of nitrogenous compounds, including ammonium and phosphate ions, as well as greenhouse gases, such as CO_2 and CH_4 [2]. These substances are released in large quantities when fertilizers are used, explaining why eutrophication and climate change are among the worst impacts [13]. The results showed that freshwater and marine eutrophication had the greatest influence on rice plantation process than land preparation and rice milling process, with the values of 0.0538 kg P eq and 0.0304 kg N eq, respectively.

Eutrophication is a process in which aquatic life is harmed by algal blooms caused by the presence of specific nutrients. Phosphates and nitrates (found in most crop fertilizers) leach into groundwater and wind up in lakes and rivers as a result of plant watering activities or rain [2]. Algae in lakes and rivers benefit from these nutrients. Algae that proliferate too quickly store a considerable amount of oxygen. Other living organisms are suffocated as a result of the lack of oxygen. These algae also block sunlight, making it impossible for aquatic plants to undergo photosynthesis. Toxins in algae can sometimes cause aquatic organisms to become poisoned. Phosphate ion (PO_4^{3-}) equivalency is used to determine eutrophication potential [18]. These calculations take into account all nutrient emissions into the soil, water, and air [29]. A biological control strategy, for example, could be used to control insect populations. Rice field flood-control measures have resulted in excessive water use and contributed to high emissions. Applying innovative technology such as alternating wetting and drying (AWD) to rice farming, for example, could significantly cut consumption [24,29,32]. Improvements in environmental performance could be made in respect to diesel usage in vehicles, tractors, and agricultural machines. Other environmentally friendly fuels, such as biofuels, could be utilized instead of diesel. The government should provide additional incentives for organic farming to improve the sustainability of rice production in Malaysia [2,29].

As in Figure 3, the life cycle of rice production for land preparation has less impact in the environment. Fuel is one of the major impacts of climate change in land preparation. This is mostly due to the usage of diesel in land preparation and harvesting machinery, as well as in vehicles used to transport harvested grains to mills. Diesel engines are employed widely in rice production gear, while gasoline is generally used in low duty equipment. Diesel is utilized to mobilize tractors during pre-season preparation and combine harvesters during the harvesting stage during the planting season. All impact categories were identified as being mainly caused by water, diesel, and electricity inputs in the rice milling process [12,16]. The rice milling process was greatly influenced by the use of electricity. Researchers face a difficult problem in maximizing energy efficiency. One of the most energy-intensive sectors is rice production. In the rice sector, husk conservation could lead to thermal energy cogeneration in furnaces for boilers and dryers [33].

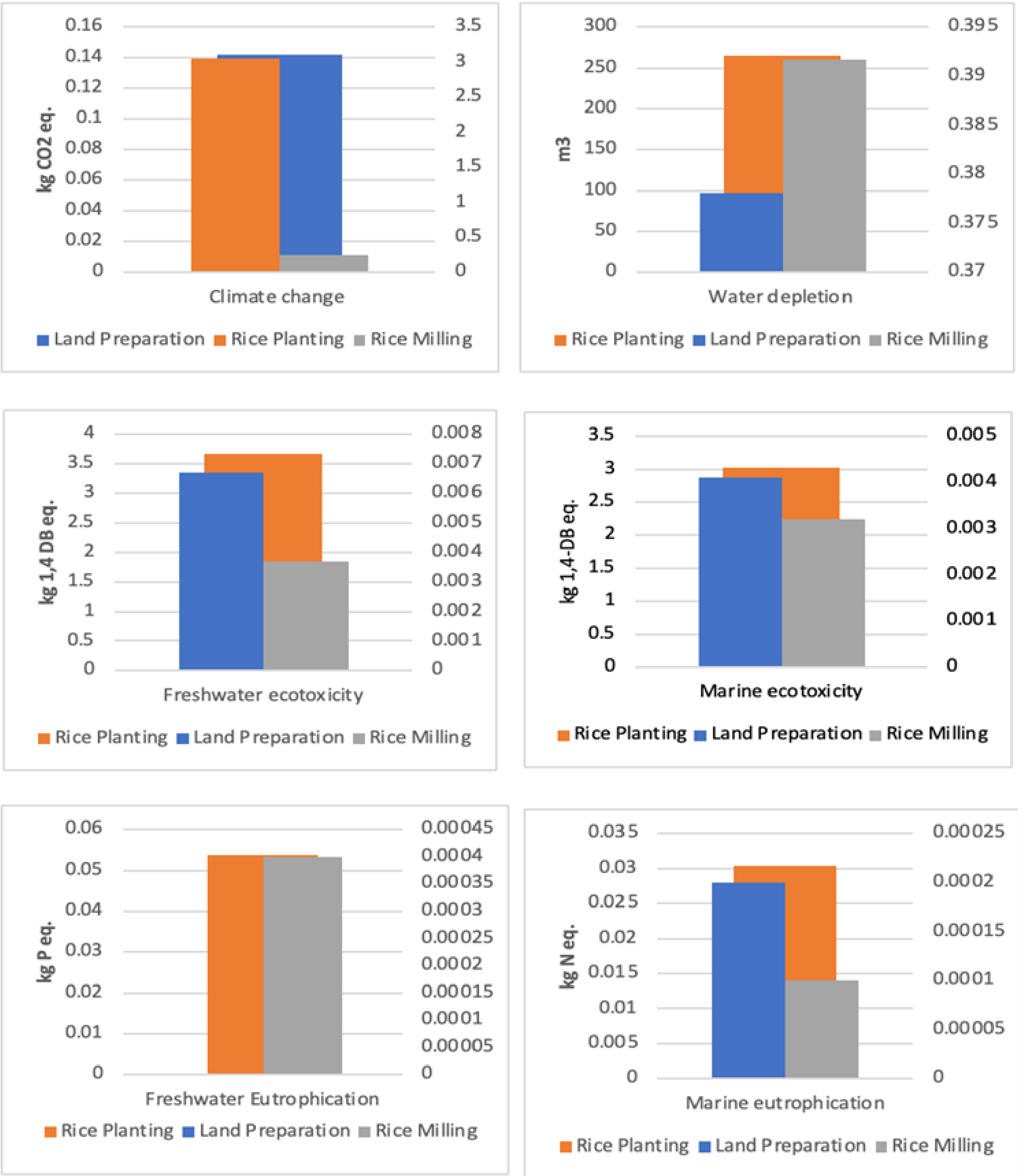

Fig. 3. Comparison of the impacts as per three phase categories

Milling is a phase that paddy goes through in the rice production process that uses a lot of energy, water, and other resources. Paddy goes through pre-cleaning, hulling, destoning, whitening, colour sorting, polishing, grading, and packaging after harvesting before reaching the consumer, where it is cooked into rice. These procedures use a lot of energy, water, and have a negative influence on the [10]. In Malaysia, several LCA studies on rice planting are accessible in the literature, however rice milling is a novel technique. Because the data was restricted, the majority of the information was based on a literature review from other countries. Most of the studies for rice milling are from Sri Lanka and Bangladesh using LCA approaches.

Because of time constraints, transportation of rice to consumers was an exception in the study. There was not much impact of climate change on diesel and the transportation of harvested grains to the mill, as well as the distance between suppliers, farms and mills was less than 15 km between destinations. Farmers will choose and send the harvested grain close to their farms since MADA has provided several districts for them to choose from. As a result, diesel use for the process did not contribute to climate change. It is important to note that these results should be interpreted with caution since they are based on European data and so reflect their environmental preferences better than our local scenarios. Nevertheless, there is always room for improvement and one way to improve is to look into alternative forms of diesel fuel that are more environmentally friendly or service the machines and vehicles regularly for improved performance.

According to the Figure 3, by using LCI for each operation, the eutrophication of freshwater and marine was determined when a wastewater quantity is specified and unspecified. There are known characteristics of the wastewater discharged from the process, including N, PO_4^{3-}, and Chemical Oxygen Demand (COD). COD from the polishing process was specified as the wastewater [34]. Wastewater from the phase's polishing, colour sorting, and whitening operations is included in the unspecified wastewater category [35]. As a result, energy conservation in the rice sector will result in a decrease in the usage of electricity, which has become a major factor in the generation process. The transportation sector in rice milling (transfer from paddy field to mill) is contributing to climate change.

Many research on the LCA of rice production have been undertaken in other countries. The cultivation stage was a hotspot in rice production, according to [2,10], with field emissions, fertiliser application, and fossil fuel usage being the main factors contributing to GHG emissions which is the value was 2.9 kg CO_2 eq per white milled rice. According to [19], Hom Mali organic rice production has an influence on climate change and water use of 2.88 kg CO_2 eq/kg paddy rice and 1.34 m^3 H_2O eq, respectively. Another study conducted also showed that most environmental impacts are from rice cultivation compared to mill, which 95% of the global warming inputs to the system are associated with the cultivation process, 2% with the harvesting process and 2% with the seeding and milling processes [36].

The demand of a flooded system was linked to water use impact. The environmental implications of rice cultivation in Korea differ dramatically from conventional, low-pesticide, non-pesticide, and organic farming approaches [37]. According to Masuda (2019), the eco-efficiency of intensive rice production in Japan may be enhanced by increasing the size of rice fields while taking into account economies of scale, farm labour outsourcing, and chemical fertiliser and pesticide cost savings. Referring to [9], the environmental effect indices for conventional rice were 10 times greater than organic rice, according to study in China. Aquatic toxicity potential and water depletion were the most important environmental indicators for conventional and organic rice, respectively. He believes that organic rice cultivation, in comparison to conventional rice cultivation, has the potential to be a more sustainable agricultural practise because organic rice production needs less water and biogenic fertiliser. It may be inferred that minimising water use, chemical fertiliser use, and fossil fuel use can improve the environmental sustainability of rice cultivation [9].

Additionally, electricity usage is one of the most significant contributors to environmental consequences. Electricity is used in all milling processes within the system boundaries of this work. According to the findings, the method has a considerable environmental impact of 0.2380 kg CO_2 eq. According to the previous studies, polishing and parboiling have different effects on milling [33]. The parboiled procedure has the greatest potential for causing global warming in the environment. Rice milling output inventories are classified as solid waste, husk, dust, and bran, which might affect air pollution. However, according to the investigation, these wastes had little impact on the ecosystem.

Some farmers, like those in other nations and Malaysia, burn straw when there are no other options. Rice straw is used as a feed for cattle and as a raw material in the packaging, paper, and paperboard production processes [35]. Paddy residue has the potential to be used as a fuel source for energy generation in Malaysia [38]. Rice production dust and bran mostly consisted of biomass from waste paddy and rice. These solid wastes have been determined to be non-toxic [35].

3.2 Sensitivity Analysis

The sensitivity analysis is crucial for identifying parameters and assumptions that influence the result more. Moreover, it is a way to simplify data collection and analyse without compromising the robustness of results. The sensitivity analysis for all process for rice production was performed in this section. Using the sensitivity analysis, a possible improvement scenario was created and quantified in order to assess the effects of the selected parameter. The sensitivity of each parameter was determined by using 20% of changes in parameter input. The parameter can be described as a sensitive parameter when the percentage of changes is above 10%.

Coincidentally, sensitivity analysis (Table 2) shows that freshwater, marine eutrophication, and water depletion show new potential impacts in the impacts category of heavy metals & carcinogens; after a 20% reduction of the number of fertilizers and pesticides applied in the process. Based on six impact categories used for the sensitivity analysis, rice plantation phase is found to be the most sensitive parameter was affected the characterized results compared to the base scenario. It may be due to inclusion of heavy metals that are modelled as long-term emissions with higher toxicity effects over longer time horizons.

Table 2
Potential environmental impacts after sensitivity analysis in rice production

Impact Category	Unit	Land Preparation	Rice Planting	Rice Milling	Total	% Reduction
Climate Change	kg CO_2 eq.	0.0000	0.4576	0.0429	0.5005	14.58
Freshwater Ecotoxicity	kg 1,4 DB eq.	0.0000	0.3279	0.0007	0.3286	8.91
Freshwater Eutrophication	kg P eq.	0.0000	0.0281	0.0001	0.0282	51.95
Marine Ecotoxicity	kg 1,4-DB eq.	0.0001	0.1624	0.0006	0.1630	5.38
Marine Eutrophication	kg N eq.	0.0000	0.0154	0.0000	0.0154	50.31
Water Depletion	m^3	0.0000	51.9904	0.0708	52.0612	19.61

Based on six impact categories used for the sensitivity analysis, chemical and water input for rice planting is found to be the most sensitive parameter. Sensitivity analysis has shown that, nitrogen is the most sensitive parameter where in most of the impacts which it scored higher the most of the impacts. Aside from that urea, phosphate and freshwater input are also found to be quite sensitive parameters which the change of freshwater eutrophication marine ecotoxicity respectively. The utilization of fertilizer such as nitrate and phosphate and pesticide such as, pretilachlor, glyposhate and metsulfuron-methyl in rice plantation significantly contributed to the environmental impact. In these phases, the use of diesel in machinery has contributed to the effects of climate change, while the use of water has contributed to the effects of water depletion. Based on the results, it can be concluded that changes in nitrogen (N) could reduce the impact of the environment as well as the application of fertilizer should be reduced in the rice production.

Referring to Yusoff and Punithawaty [2], higher impact scores in ecotoxicity results are due to uncertainties, and the study includes the unknown amount of inert ingredients in the pesticides and the heavy metal emissions as a result. According to the earlier discussion, the unknown chemical make-up of the pesticides led to the need for the cut-off criteria to continue carrying out the LCA.

Inadvertently, this may have led to several impact categories being missed, as seen in the sensitivity analysis. Therefore, it is important to note that the results were based on European characterization factors, and this assumption might have influenced the accuracy and representativeness of the results. Despite the assumptions, the results from the study still stand.

4. Conclusions

A life cycle assessment approach was used to assess the environmental impacts of rice production in the Muda Granary area of Kedah. Variations in environmental impacts were observed based on the impact category. We identified a few factors that affected environmental impacts significantly. Due to the usage of fertilizers and pesticides in the rice plantation process, the rice plantation process has a relatively greater impact on the environment than other processes. Rice plantations use a lot of nitrogen fertilizer and phosphate fertilizer, and they are likely causing higher environmental impacts, especially with climate change. A significant source of N was the high fertilizer input, which was often much more than what was really needed for the crop. The production of nitrogen fertilizer is energy-intensive and emits large quantities of SO_2 and CO_2. Furthermore, excessive fertilizer consumption can lead to large NH_3 emissions and N losses in arable farming subsystems.

As a result of the high input-based rice production practice in Muda region, particularly the overuse of nitrogen fertilizers and irrigation water, N losses have been excessive, water has been depleted, and pollutant emissions have been generated, making this practice environmentally unsound and unlikely to be sustainable. It is therefore concluded that rice production systems can achieve improved environmental performance by using fertilizers whose NH_3 volatilization rates are low (e.g., NH_4NO_3) that are applied according to crop needs to minimize NH_3 volatilization and N and P runoff losses [13]. Enhancing water management, especially during the early stages of growth, and reducing paddy field irrigation water discharge are also significant measures to minimize N and P runoff losses. It is necessary to investigate the excessive quantity of fertilizers used by the paddy farm in the case study (more than 60% above that recommended by Yusoff and Panchakaran) as it constitutes one of the leading causes of eutrophication and global warming. Following a discussion with the farm operators, it is evident that they do not seem to know what the appropriate amount to use is; they make use of all the fertilizers provided to them under the MADA subsidy. During the rice plantation phase, the chosen farm applied pesticides that caused marine and freshwater ecotoxicity. However, results are to be treated with caution. This is because information on all inert ingredients could not be obtained due to trade secrets. As a result, despite literature proving their presence, harmful solvents or heavy metals could not be identified. The results from the sensitivity analysis validate these findings. The study finds that paddy cultivation is an environmental hotspot. To become self-sufficient in rice production, future LCA studies should be conducted on rice production (specifically paddy cultivation and nutritional management) in addition to field managements to better assess and quantify the environmental impacts in order to generate concrete recommendations for nutrient management.

Additionally, the government should pursue reductions of GHG emissions in key areas, such as agriculture. Thus, this study could support government initiatives and serve as a guideline for sustainable rice production. As a result, the LCA method is very useful since it can determine the impacts on humans, ecosystems, and resources. Various parties, including policymakers, producers, and consumers, can use this method to choose sustainable products. In addition, the LCA method can be used as guidelines in choosing the type of fertilizers, pesticides, or other inputs. This is because this method clearly shows the difference in emissions produced with the applications of different inputs so that environmental impacts can be reduced. There were significant limitations to this study, including a lack of data for chemical inputs and emissions, as well as limited data availability that required estimates; there were also time limits, a lack of local references, and a lack of national databases. This study's database, for example, was derived from European databases. As a result, the accuracy and representativeness of the produced results may have been harmed. As a result of the absence of access to national databases, the results obtained may not accurately reflect Malaysia's possible impacts. Furthermore, because this study focused solely on environmental performance at the farm gate, it is suggested that additional LCA research be undertaken for other stages of rice production.

Due to Malaysia's reliance on key granary areas, the performance of rice production is important. Finally, this research contributes to the agriculture sector in Malaysia by providing helpful information. This study's findings could be used as a blueprint for achieving food production sustainability. It might also be used to help policymakers and farmers in Malaysia implement more ecologically friendly rice growing methods. However, further LCA studies on rice production are needed to acquire more knowledge on rice field management, which might lead to more initiatives and efforts to improve the rice sector's sustainability. Furthermore, further primary research on the LCA of rice milling in Malaysia is needed to provide a more comprehensive assessment of environmental effect. The findings of this study back up Malaysia's National Agro-Food Policy 2011–2020, which aims to address food security and safety while also ensuring the agro food industry's long-term viability. Because of the broad use of LCA, it is well suited to analysing the environmental performance of rice production in other rice-producing countries around the world, particularly in Southeast Asia. There is not much discussion on the impact assessment of rice milling process due to lack of prior studies on the topic. Besides, the scope of the analysis in this study was limited since most of the data required are not easy to access due to business confidentiality concern. As time was the constraint for this study, it can serve as an important opportunity to identify new gaps in the literature and to describe the need for further studies.

Acknowledgement

This research was funded by a grant Q.J130000.3601.03M25 and R.J130000.7301.4B704, supported by the UTM Research University Grant, and the Universiti Teknologi Malaysia.

References

[1] Omar, Sarena Che, Ashraf Shaharudin, and Siti Aiysyah Tumin. "The status of the paddy and rice industry in Malaysia." *Khazanah Research Institute. Kuala Lumpur* (2019).

[2] Yusoff, Sumiani, and Punithawaty Panchakaran. "Life cycle assessment on paddy cultivation in Malaysia: A case study in Kedah." *LCA Rice* (2015): 1-10.

[3] Chapagain, Ashok K., and Arjen Y. Hoekstra. "The blue, green and grey water footprint of rice from production and consumption perspectives." *Ecological Economics* 70, no. 4 (2011): 749-758. https://doi.org/10.1016/j.ecolecon.2010.11.012

[4] CO, Akinbile, K. Abd El-Latif, Rozi Abdullah, and M. Yusoff. "Rice production and water use efficiency for self-sufficiency in Malaysia: a review." *Trends in Applied Sciences Research* 6, no. 10 (2011): 1127-1140. https://doi.org/10.3923/tasr.2011.1127.1140

[5] Akinbile, Christopher O., and Abimbola Y. Sangodoyin. "Crop water use responses of upland rice to differential water distribution under sprinkler irrigation system." *Pacific Journal of Science and Technology* 12, no. 1 (2011): 516-526.

[6] Hoekstra, Arjen Y. "A critique on the water-scarcity weighted water footprint in LCA." *Ecological indicators* 66 (2016): 564-573. https://doi.org/10.1016/j.ecolind.2016.02.026

[7] Jirapornvaree, Ittisak, Tawadchai Suppadit, and Vikas Kumar. "Assessing the environmental impacts of agrifood production." *Clean Technologies and Environmental Policy* (2021): 1-14. https://doi.org/10.1007/s10098-021-02153-5

[8] Montzka, Stephen A., Edward J. Dlugokencky, and James H. Butler. "Non-CO2 greenhouse gases and climate change." *Nature* 476, no. 7358 (2011): 43-50. https://doi.org/10.1038/nature10322
[9] He, Xueqing, Yuhui Qiao, Long Liang, Marie Trydeman Knudsen, and Friederike Martin. "Environmental life cycle assessment of long-term organic rice production in subtropical China." *Journal of Cleaner Production* 176 (2018): 880-888. https://doi.org/10.1016/j.jclepro.2017.12.045
[10] Blengini, Gian Andrea, and Mirko Busto. "The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy)." *Journal of environmental management* 90, no. 3 (2009): 1512-1522. https://doi.org/10.1016/j.jenvman.2008.10.006
[11] Yodkhum, Sanwasan, Shabbir H. Gheewala, and Sate Sampattagul. "Life cycle GHG evaluation of organic rice production in northern Thailand." *Journal of Environmental Management* 196 (2017): 217-223. https://doi.org/10.1016/j.jenvman.2017.03.004
[12] Brodt, Sonja, Alissa Kendall, Yaser Mohammadi, Aslihan Arslan, Juhong Yuan, In-Sung Lee, and Bruce Linquist. "Life cycle greenhouse gas emissions in California rice production." *Field Crops Research* 169 (2014): 89-98. https://doi.org/10.1016/j.fcr.2014.09.007
[13] Wang, Mingxin, Xunfeng Xia, Qianjin Zhang, and Jianguo Liu. "Life cycle assessment of a rice production system in Taihu region, China." *International Journal of Sustainable Development & World Ecology* 17, no. 2 (2010): 157-161. https://doi.org/10.1080/13504501003594224
[14] Xu, Xiaoming, Bo Zhang, Yong Liu, Yanni Xue, and Binsheng Di. "Carbon footprints of rice production in five typical rice districts in China." *Acta Ecologica Sinica* 33, no. 4 (2013): 227-232. https://doi.org/10.1016/j.chnaes.2013.05.010
[15] Hokazono, S., K. Hayashi, and M. Sato. "Potentialities of organic and sustainable rice production in Japan from a life cycle perspective." *Agronomy Research* 7, no. 1 (2009): 257-262.
[16] Van Hung, Nguyen, Maria Victoria Migo, Reianne Quilloy, Pauline Chivenge, and Martin Gummert. "Life cycle assessment applied in rice production and residue management." *Sustainable rice straw management* (2020): 161-174. https://doi.org/10.1007/978-3-030-32373-8_10
[17] Owens, J. W. "Water resources in life-cycle impact assessment: considerations in choosing category indicators." *Journal of industrial Ecology* 5, no. 2 (2001): 37-54. https://doi.org/10.1162/10881980152830123
[18] Jirapornvaree, Ittisak, Tawadchai Suppadit, and Vikas Kumar. "Assessing the environmental impacts of agrifood production." *Clean Technologies and Environmental Policy* (2021): 1-14. https://doi.org/10.1007/s10098-021-02153-5
[19] Mungkung, Rattanawan, Patthra Pengthamkeerati, Ratcha Chaichana, Saranya Watcharothai, Kittiwan Kitpakornsanti, and Supachok Tapananont. "Life Cycle Assessment of Thai organic Hom Mali rice to evaluate the climate change, water use and biodiversity impacts." *Journal of Cleaner Production* 211 (2019): 687-694. https://doi.org/10.1016/j.jclepro.2018.11.197
[20] Breiling, Meinhard, Tatsuo Hoshino, and Ryuji Matsuhashi. "Contributions of Rice Production to Japanese Greenhouse Gas Emissions Applying Life Cycle Assessment as a Methodology." *The University of Tokyo, Japan* (1999).
[21] Yung, CHEE LIANG, Vijaya Subramaniam, and Sumiani Yusoff. "Life cycle assessment for the production of palm biodiesel." *Journal of Oil Palm Research* 33, no. 1 (2021): 140-150. https://doi.org/10.21894/jopr.2020.0080
[22] Hanafiah, Marlia M., Nor Fadillah Ghazali, Siti Norliyana Harun, Hayder Saadoon Abdulaali, Mahmood J. AbdulHasan, and Mohd Khairul Amri Kamarudin. "Assessing water scarcity in Malaysia: a case study of rice production." *Desalination and water Treatment* 149 (2019): 274-287. https://doi.org/10.5004/dwt.2019.23841
[23] Mohamed, Zainalabidin, Rika Terano, Mad Nasir Shamsudin, and Ismail Abd Latif. "Paddy farmers' sustainability practices in granary areas in Malaysia." *Resources* 5, no. 2 (2016): 17. https://doi.org/10.3390/resources5020017
[24] Rahman, Mohammad Hariz Abdul, Sau Soon Chen, Putri Razreena Abdul Razak, Nurul Ain Abu Bakar, Mohammad Shahid Shahrun, Norziana Zin Zawawi, Azzami Adam Muhamad Mujab *et al.,* "Life cycle assessment in conventional rice farming system: Estimation of greenhouse gas emissions using cradle-to-gate approach." *Journal of Cleaner Production* 212 (2019): 1526-1535. https://doi.org/10.1016/j.jclepro.2018.12.062
[25] Yong, Jiunn Boon, Lian See Tan, and Jully Tan. "Comparative life cycle assessment of biomass-based and coal-based activated carbon production." *Progress in Energy and Environment* (2022): 1-15. https://doi.org/10.37934/progee.20.1.115
[26] Boulay, Anne Marie, and Stephan Pfister. "ISO 14046 Water Footprinting and Water Impact Assessment in LCA: Adjusted from UNEP Training Materials on Water Footprint (Pfister and Boulay 2013)." *LCA XIII– Orlando – Septembre 30th (2013)*, 219. http://www.wulca-waterlca.org/pdf/Water_Footprint_class_LCAXIII_2013.pdf.
[27] Nemecek, T., X. Bengoa, J. Lansche, P. Mouron, V. Rossi, and S. Humbert. "Methodological guidelines for the life cycle inventory of agricultural products." *World Food LCA Database (WFLDB). Quantis and Agroscope, Version* 2 (2014).

[28] Golsteijn, Laura, Rimousky Menkveld, Henry King, Christine Schneider, Diederik Schowanek, and Sascha Nissen. "A compilation of life cycle studies for six household detergent product categories in Europe: the basis for product-specific AISE Charter Advanced Sustainability Profiles." *Environmental Sciences Europe* 27 (2015): 1-12. https://doi.org/10.1186/s12302-015-0055-4

[29] Harun, Siti Norliyana, Marlia M. Hanafiah, and Nur Izzah Hamna Abd Aziz. "An LCA-based environmental performance of rice production for developing a sustainable agri-food system in Malaysia." *Environmental management* 67 (2021): 146-161. https://doi.org/10.1007/s00267-020-01365-7

[30] Huang, Shan, Wenyi Rui, Xianxian Peng, Qianru Huang, and Weijian Zhang. "Organic carbon fractions affected by long-term fertilization in a subtropical paddy soil." *Nutrient Cycling in Agroecosystems* 86 (2010): 153-160. https://doi.org/10.1007/s10705-009-9279-2

[31] SUN, Bin-feng, Z. H. A. O. Hong, Yi-zhong LÜ, L. U. Fei, and Xiao-ke WANG. "The effects of nitrogen fertilizer application on methane and nitrous oxide emission/uptake in Chinese croplands." *Journal of Integrative Agriculture* 15, no. 2 (2016): 440-450. https://doi.org/10.1016/S2095-3119(15)61063-2

[32] Kounina, Anna, Manuele Margni, Jean-Baptiste Bayart, Anne-Marie Boulay, Markus Berger, Cecile Bulle, Rolf Frischknecht *et al.,* "Review of methods addressing freshwater use in life cycle inventory and impact assessment." *The International Journal of Life Cycle Assessment* 18 (2013): 707-721. https://doi.org/10.1007/s11367-012-0519-3

[33] Kamalakkannan, S., and Asela K. Kulatunga. "Life cycle assessment of rice processing." In *International Conference on Industrial Engineering and Operations Management*, pp. 3417-3424. 2018.

[34] Ariyarathna, S. M. W. T. P. K., H. P. D. S. N. Siriwardhana, and M. Danthurebandara. "Life cycle assessment of rice processing in Sri Lanka: Modern and conventional processing." In *2016 Moratuwa Engineering Research Conference (MERCon)*, pp. 297-302. IEEE, 2016. https://doi.org/10.1109/MERCon.2016.7480157

[35] Nadeeshani, E., and M. Y. Gunasekera. "Environmental performance comparison of parboiled rice production." (2020).

[36] Kasmaprapruet, Sakaorat, Woranee Paengjuntuek, Phanida Saikhwan, and Harnpon Phungrassami. "Life cycle assessment of milled rice production: case study in Thailand." *European Journal of Scientific Research* 30, no. 2 (2009): 195-203.

[37] Kim, Sang-Min, Moon-Seong Kang, and Min-Won Jang. "Assessment of agricultural drought vulnerability to climate change at a municipal level in South Korea." *Paddy and Water Environment* 16 (2018): 699-714. https://doi.org/10.1007/s10333-018-0661-z

[38] Mohd Shafie, Shafini. "Paddy residue based power generation in Malaysia: Environmental assessment using LCA approach." *ARPN Journal of Engineering and Applied Sciences* 10, no. 15 (2015): 6643-6648.