Life cycle assessment on paddy cultivation in Malaysia: A case study in Kedah

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Abstract

Purpose This LCA study was conducted to investigate the environmental impacts of rice production in a chosen paddy field in Kedah at a low-lying plain, focusing on the paddy cultivation stages (cradle-to-gate). The study was done to identify the environmental impacts when different pesticides and fertilizers are used and also to see how gravely it impacts the region when the results are extrapolated for Peninsular Malaysia. The results obtained may be used to make informed recommendations with regards to pesticide and fertilizer use to reduce environmental impact with the farmers being the intended audience.

Methods The functional unit is defined as 1 metric tonnes (MT) of paddy grains harvested. Primary data used was supplied by the chosen paddy farm in Kedah and secondary data includes the material safety data sheets (MSDS), JEMAI database and literature. 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. Extrapolation of farm-level data to regional-level data was then performed using the top two impact categories identified.

Results and Discussion Results from both the Eco-Indicator 95 and LIME impact assessment methods concur that the top impact categories are global warming and eutrophication with the LIME method also showing fossil fuel resource consumption as a high impact category as well. The sensitivity analysis showed that the increase of solvents did not greatly change the impact assessment results.

Conclusions The study concludes that the greatest impacts of rice production in a chosen paddy farm in Kedah are from fossil fuel consumption (1715MJ per 1MT of paddy grain harvested), global warming (298 kg CO_2 eq./1MT paddy) and eutrophication (29.3 kg PO_4 eq./1MT paddy). It is learnt that the quantity of fertilizers used were excessive and must be looked into. Alternately, the pesticides used were in very small quantities and so, no real adverse effects were detected. It is hoped that the results obtained would be a good basis for more LCA research to further look into the paddy cultivation methods, especially in the nutrient management stage of the planting process.

Keywords Life Cycle Assessment (LCA) · Paddy cultivation · Rice · Nutrition Management · Extrapolation.

1 Introduction

Rice is a crucial part of everyday Malaysian diet. In 2011, Malaysia produced 1.66 million metric tons of rice while statistics show that worldwide production was at 36.3 million metric tonnes (DOA, 2014). This shows that the Malaysian production is only approximately 0.4% of the total world rice production. Up until recent years, Malaysia still only produces around 70% of what it needs to support itself and must import the rest, mostly from Thailand and Vietnam. The average Malaysian citizen consumes 82.3 kilograms of rice per year. 1 hectare of paddy field produces on average 3.7 metric ton (MT) of rice. The increasing population is calling for more research and technological advancement to increase rice production for consumption within the nation. Machineries, fertilizers, and pesticides are widely used to increase production of rice, but at the same time these techniques can cause adverse environmental impacts. Major environmental concerns from rice plantation include emission of greenhouse gases, eutrophication, and acidification (Brodt et al., 2014; Wang, Xia, Zhang, & Liu, 2010).

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 (Xu, Zhang, Liu, Xue, & Di, 2013). 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 Hoshino et al. (1999) and Hokazono et al. (2009) were among the LCA studies conducted on rice production in Japan that aimed at identifying best practices that would curb greenhouse gas emissions. However, often times these studies tend to simplify the type and quantity of chemicals involved in rice production, particularly in the crop nutrition management stage. Subsequently, there has been little information provided concerning how these chemical may actually impact the environment in terms of human toxicity and eco toxicity. 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.

This study aims to specifically identify and quantify the environmental impacts of paddy cultivation based on a chosen paddy field in Kedah, Malaysia. 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 from the land preparation stage up to the harvesting stage. This will include seed sowing as well as fertilizer and pesticide application. 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, namely Peninsular Malaysia. This geographical extrapolation plays a key role in postulating the gravity of these impacts to the region so that a clear picture can be painted on what the damages may be and what needs to be done. As this study focuses on lowland paddy cultivation, efforts will be made to ascertain that similar land preparation, planting, crop management and harvesting methods are used in low-lying paddy fields throughout Peninsular Malaysia. This is to ensure the credibility of the results from the extrapolation of farm-level data to regional-level data.

2 Methods

2.1 Goal and scope

The goal of this LCA study is to investigate the environmental impacts of rice production in a chosen paddy field in Kedah, focusing on the paddy cultivation stages which include land preparation to harvesting. The rice milling stage has been excluded from this LCA study due to time constraints as well as lack of data. Special attention was given to identify the environmental impacts of pesticides and fertilizers used during the nutrition management stage in the cultivation process. The results of the study are intended to be used to make informed recommendations with regards to pesticide and fertilizer use to reduce environmental impact with the farmer being the intended audience. This is in hopes that they will then be able to make environmentally smarter decisions to achieve sustainable rice farming. The functional unit for this study is 1 metric tonne (MT) of harvested paddy grains. This LCA study is limited from cradle-to-gate. Figure 1 provides a graphic display of the system boundary. The energy input is limited to the use of agricultural equipment during the land preparation and harvesting stages as well as from the use of transportation in and out of the farm. The chemical input, namely the pesticides and fertilizers used, are found in the sprout planting stage. The emissions, specifically to the air and water, at each stage of the process were also taken into account.

Data such as the compositions and the percentage of chemicals used as ingredients in the production of the fertilizers and pesticides are a trade secret and this proved to be a major limitation. Thus, necessary assumptions were made using secondary data retrieved from scientific journals, material safety data sheet, etc.

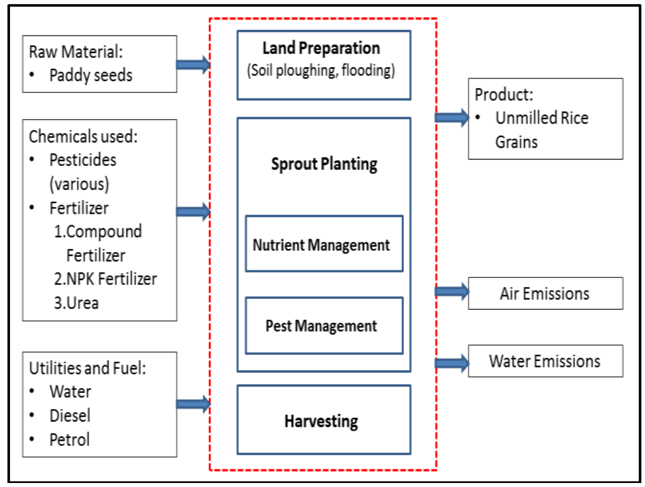


Fig. 1 System Boundary for Cradle-to-Gate Rice Production

The key assumptions that need to be highlighted are the assumptions made in the cut-off criteria. The cut-off criteria were developed on the basis of simplifying the life cycle inventory process due to time constraints and data limitations. The cut-off criteria chosen in this LCA study is *any chemical components that forms less than 5% of the pesticide composition is assumed to have negligible effect on the environment, hence they are not included in this study*. In addition, any ingredients that are not identified from the MSDS are assumed to be lower than 5% in composition or they do not pose an environmental threat. The assumptions made in the critical cut-off rule will be the subject of the sensitivity analysis. This is because numerous reports from the EPA state that there are many heavy metals and highly toxic organic compounds within pesticides. These components are not included in the label since the pesticide suppliers are not required to divulge such ingredient by law. The release of such sensitive information could potentially trigger a public health issue which can be detrimental to the company (Cox, 1999).

Another major assumption is related to the limitation of emission data. The methodology used to formulate the emission components assumes that each chemical constituents of the pesticide were biologically degraded completely into basic chemical components such as CO_2, NO_x, SO_x, etc. This simplified fate and transport mechanism of pesticide is flawed in many ways. First, there is a wide variety of pathways for an organic matter to degrade, thus there is a potential for a pesticide to convert into something more toxic. Moreover, the rate at which the organic matter become degraded are not considered as well. These two key limitations may lead to an LCIA result that is not truly reflective of the situation. However, these drawbacks were unavoidable given the time constraints and the lack of data availability.

2.2 Life cycle inventory analysis

The quality of the data obtained ultimately influences the quality of the LCA study results. Data collection was a tedious and time consuming process but nevertheless crucial in order to gain the most credible and representative data available. All of the raw information obtained in this study was obtained directly from the owners of the rice plantation chosen in this study. Data on rice production outputs, chemical use, size of plantation and information regarding farming machinery, transportation of raw materials to the farm and transportation of products out of the farm were available from 2007 to 2014. Unfortunately, the quantity and quality of the data were not consistent from year to year. Therefore, based on the availability of information, this LCA study chose to conduct the investigation based on the 2011 data, it being the most recent year with the best quantity and quality of data.

Purchase receipts were used to derive information on chemicals while contract workers who owned the agricultural machineries were interviewed to obtain the energy data. However, these primary data could not be immediately entered into the JEMAI software without a series of adjustments. As a result, the raw data had to be transformed to obtain the mass of chemical inputs as well as suitable energy inputs that can be keyed into JEMAI. The alteration of these raw data were made through secondary sources such as scientific journals, material safety data sheet (MSDS) and phone calls to Muda Agricultural Development Authority (MADA).

Chemical input and output Pesticide as well fertilizer inputs and outputs were only pertinent in the sprout planting stage. The pursuit of obtaining the most credible data for pesticide input was by far the step that consumed the most amount of effort in this study. This is mainly due to the fact that the pesticide manufacturing industry is heavily guarded by its players and information on each of its ingredients was sparse. According to the U.S. Environmental Protection Agency (EPA), pesticide companies are only required to display the active ingredients on their labels based on the Federal Insecticide, Fungicide, and Rodenticide Act (EPA, 2014). Inert ingredients, which may include some heavy metals and solvents that can harm the environment, are not required to be displayed. This lack of information and the lack of LCA studies on individual pesticides led to a difficulty in obtaining relevant pesticide data for the purpose of inventory calculations by the software. Whilst information on the type and quantity of the pesticides was readily obtained from the farm owner, it was not compatible for use in JEMAI and so input and output data were calculated and estimated using material safety data sheets and relevant scientific journals as a guide.

The ingredients of each pesticide were obtained mainly through the corporate MSDS. As there are various MSDS available on the internet for any particular pesticide, the one that had the most active and inert ingredients listed were selected after it was verified for data consistency with other MSDS sources. Key information extracted from pesticide's MSDS includes active ingredients, inert ingredients, percentage composition of each ingredient (w/w%), density of each ingredient (only for pesticide in aqueous form) and the chemical formula of each ingredient. This set of information is used to calculate the mass units of every chemical input. The following equations were used to work out the mass in accordance to the functional unit of 1MT of harvested paddy grains.

Eqn. 1: $$\mathbf{P \times S = C}$$

Eqn. 2: $$\mathbf{\frac{C \times D}{1000} = I}$$

Eqn. 3: $$\mathbf{\frac{I \times 1000}{9260} = \text{Chemical Input (kg)}}$$

Where, C = Volume of chemical constituents (mL)
P = Total raw quantity of pesticide (mL)
S = Percentage of chemical composition (%)
D = Density of chemical constituents (g/cm3)
I = Total chemical input (kg)

As the emissions data for the pesticides were not available, they were derived through a series of calculations and estimations based on theories provided by scientific journals. Two main scientific journals were used as the basis on formulating the emissions component of the pesticides following a thorough research. A summary of how these two journals contributed to this are as follows:

i) Jones (1995) from the Department of Pesticide Regulation in Sacramento, California conducted a study on the environmental fate of insecticide cypermethrin and found that the fate of the insecticide is mostly found in soil and water. The insecticide is biologically degraded in soil to form various intermediate organic compounds via microbial oxidation. Eventually, these organic compounds are broken down into basic components mainly being CO_2. The presence of cypermethrin in the air is limited due to the low volatility of the compound and its resistance to photodegradation.

ii) A study conducted by Bodegom et al. (2001) further reinforces Jones' findings. This study shows that the ultimate fate of pesticide through microbial degradation would include basic compounds such as NOx, SOx, CH_4, CO_2, and various others depending on the chemical formula of the pesticide. More importantly, the study shows that methane emissions are dependent on the amount of CO_2 are present in the soil. The study concluded that as a general rule, the concentration of CH_4 and CO_2 are present in equal amounts under anaerobic conditions at 30°C, which is representative of Malaysia's rice paddy fields.

By combining these theories mentioned above, this investigation has proposed a series of emission components (ie. SOx, NOx and CH_4) that is relevant to each pesticide. The emissions data were calculated by applying mass balance and some basic chemistry. Essentially, a balanced chemical equation based on microbial respiration (an oxidation reaction) was used as suggested by Jones (1995) and Bodegom, et al. (2001) and is as follows:

Eqn. 4 $$\mathbf{\text{Organic Material} + O_2 \rightarrow CO_2 + SO_2 + NO_2 + H_2O\ldots}$$

By knowing the chemical formula of each chemical input, the molecular mass of each pesticide can be calculated and converted into moles using equation 5. Once this was known, the number of moles of each emission component, which is dependent on the mole ratio of the balanced chemical equation, was calculated. The mass of each emission component was then calculated by rearranging equation 5 and this is succeeded by functional unit calculations using equation 3. The data is then entered as emission outputs in JEMAI.

Eqn. 5 $$\textbf{Moles of organic material} = \frac{\textbf{mass of organic material}}{\textbf{molecular mass}}$$

Inputs for chemicals in fertilizers are all in the form of primary data. Similar to the limitations faced with pesticides, the emissions data for fertilizers were not available. Therefore the methodology to calculate emissions data for pesticides was repeated again using fertilizer data. The same scientific journals by Jones (1995) and Bodegom (2001) were used as a guide. Delivery receipts from MADA provided the raw data for the fertilizer, such as the brand name, quantity of bags and the weight of each bag. With this information in hand, MADA furnished details on the ingredients of each brand of fertilizer as well as its chemical components and percentage composition. These chemical components do not add to 100%, thus the chemical components not identified by MADA are assumed to have a negligible impact to the environment. The fertilizer input is converted into functional units using equation 3 while the output emissions data was obtained using the same means previously employed for pesticides.

Methane emissions are calculated differently from the other output data because methane production is a side effect of the rice cultivation process. During rice cultivation, the paddy fields are flooded with water, which prevents oxygen from entering the soil. Consequently, the anaerobic conditions would result in methanogenesis; a process where microbes undergo anaerobic respiration. The formation of methane is a two-step process as shown below:

$$\mathbf{CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O}$$
$$\mathbf{CH_3COOH \rightarrow CH_4 + CO_2}$$

As mentioned in the study by Bodegom et al (2001), the concentration of CH_4 and CO_2 are roughly equivalent under Malaysian weather. The moles of CO_2 emissions are halved and attributed to CH4 emissions.

Energy A variety of energy data is required at different stages in the rice cultivation process flow. The tractors were used during land preparation. A harvester was used during the harvesting seasons. Lorries were used to transport seeds, fertilizers, and harvested paddy grains between the farm, the mills, and the suppliers. Raw energy data were mainly collected through business transaction receipts from rice mills or phone interview with agricultural machinery operators. JEMAI is capable of computing energy data for transportation modes such as lorry and car. The only information needed for JEMAI is the weight of the transport used and the distance covered. Information for the weight of the car and lorry were provided by the mills during the delivery of harvested rice. Appendix C provides detailed information on raw data collection and subsequent calculation.

As JEMAI was not able to compute agricultural processes, the emissions data for tractor and harvester activities were calculated with the aid of a study on mobile combustion by the EPA (2008). The machine operators supplied information concerning fuel efficiency, type of fuel, and operating time for each machine. These raw data were used to calculate the necessary emissions data via the following steps:

i) The total fuel consumption in a season was calculated by knowing the fuel efficiency and size of farm.
ii) Air pollutants emitted from agricultural machineries were identified based on the study by the EPA (2008).
iii) Amount of air pollutants emitted was calculated by total fuel consumed in functional units multiplied by the rate of pollutant emitted per litre of fuel consumed, which is obtained from the said study.

2.2 Life cycle impact assessment

Two modelling methods have been chosen to study the impacts from the rice planting process. One is the Eco Indicator 95 from Europe, which is a mid-point impact assessment model. The second is the Life Cycle Impact Assessment Method based on End Point Modelling, otherwise known as LIME, which is from Japan. Both these methods are equipped in the JEMAI LCA Pro ver. 2.1.2 software that was used in this LCA study. Due to the lack of LCIA software and local modelling methods in Malaysia, these two methods were adopted and used instead. The LIME method was chosen as it was modelled based on an Asian socio-environment; the closest to the local scenario out of all the other methods. Meanwhile, the European based Eco Indicator 95 was used to see if the different environmental priorities in these two regions will bring about a different set of results in the LCIA or resonate with each other to give a sound conclusion. Classification and characterization, being mandatory elements under the ISO 14040 series, were done via both methods. Following this, normalization and weighting analysis were also performed as well as a damage assessment via LIME. Although these steps are optional elements according to the standards, it was done nevertheless to give concrete support to the final findings.

2.3 Sensitivity analysis

Focus was given to performing a sensitivity check due to the key assumption made in the scope definition regarding the cut-off criteria, which states that any chemical component that forms less than 5% of the pesticide composition is assumed to have negligible effect on the environment and so, they were not included in this study. However, previous studies (Khoshnevisan et al., 2014;

Margni, Rossier, Crettaz, & Jolliet, 2002; van Zelm, Larrey-Lassalle, & Roux, 2014) show that a large percentage of solvent and small amounts of heavy metal are found in pesticides. These constituents are unfortunately hidden due to trade secrets. Therefore, a sensitivity analysis was performed by increasing the amount of inert substances by 15% for solvents and by adding in very small quantities of heavy metal (As, Pb, Cd). The change in the LCIA was analysed using the same two methods, LIME and Eco-Indicator 95 to see if there are any large variations in the results from the initial study.

2.4 Extrapolation of farm-level data to national-level data

One way to quickly understand the environmental impacts from rice farming on a larger perspective, be it regional or national, is to perform a geographical extrapolation of the findings from the existing life cycle impact assessment done for the farm. Ideally, it would be best to perform a detailed LCA study on more farms throughout the country and then using the obtained results to reflect a regional or national average. Unfortunately due to time and resource constraints, such methods were not feasible in this study. Nevertheless, the method shown below was used for a simple extrapolation in an endeavour to assess in a simplified manner the regional or national impact. The intention was purely to drive home the implications rice farming may have on the environment by highlighting the impact hot spots during the paddy cultivation stage. Undeniably, rice farming is not the predominant crop grown in Malaysia but due to growing population demands and underused local resources such as suitable climate and soil fertility, there is much effort being put to grow this industry in hopes Malaysia will become a more self-sustaining country for growing rice and not rely so much of rice imports.

Typically in attempting an extrapolation of a farming region, the total impact is usually presumed as the sum of impacts for every farm in the region. Before extrapolating the results obtained from a farm to a region, it must be ensured that farming practices within the region are similar. Once impacts results were obtained, the following equation may be used to calculate the regional impact. This simple mathematical model was adapted from a study done by Nemecek et al., 2012, where geographical extrapolation was conducted to understand global warming potential of worldwide agriculture.

Eqn. 6 $$\mathbf{RLEI = FLEI \times \frac{Yr}{Yf}}$$

Where, RLEI = Regional Level Environmental Impact (kg/1MT paddy)
FLEI = Farm Level Environmental Impact (kg/1MT paddy)
Yr = Regional Yield (MT)
Yf = Farm Yield (MT)

3 Results and discussion

3.1 Results from the Eco Indicator 95 (Eco 95) Method

The total life cycle impacts of 1MT of paddy harvested are shown in Table 1. Based on the results obtained, it is evident that the greenhouse effect impact was the highest recorded with 228 kg CO_2 equivalent. The main contributors in this category is CO_2 (71%) followed by CH_4 (28%) and the remaining 1% is N_2O as shown in Figure 2. This is followed by the eutrophication impact, with 27 kg phosphate equivalent in 2011. The greatest contributor in this category is phosphate followed by ammonium ions as seen in Figure 3.

Table 1 Characterization results of environmental impact assessment of 1MT of paddy harvested using Eco 95

Impact category	Indicator result	Characterization model	Unit
Greenhouse effect	2.28E+02	GWP	CO2 eq. kg
Ozone layer depletion		ODP	CFC eq. kg
Acidification	1.77E-01	AP	SO2 eq. kg
Eutrophication	2.70E+01	NP	Phosphate eq. kg
Summer smog	4.30E-02	POCP	ethene eq. kg
Winter smog	6.70E-02	1 / EQS	SO2 eq. kg
Pesticides	1.00E-01	-	kg
Heavy metals		1 / EQS	Pb eq. kg
Carcinogenics		1 / EQS	PAH eq. kg

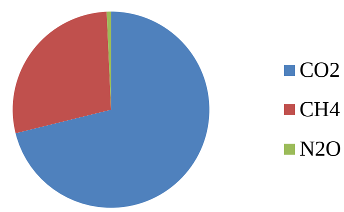


Fig. 2 Contributors to greenhouse gas (GHG) emissions (CO_2 kg equivalent)

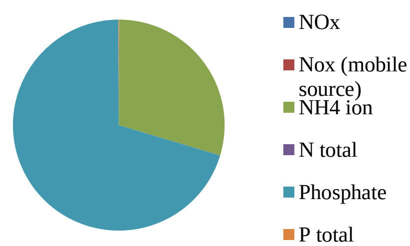


Fig. 3 Contributors to Eutrophication Potential (EP) (PO_4 kg equivalent)

As this characterization model is based on European scenario, winter and summer smog impacts were observed, with winter being slightly higher. The consumption of fossil fuels and release of aerosols leads to the presence of smog and in the winter, the temperature inversion prevents the smog from escaping into the upper atmosphere, thus causing higher impact potential.

3.2 Results from the Life Cycle Impact Assessment Method based on End Point Modelling (LIME)

Characterization Table 2 shows the chosen impact categories, its corresponding characterization models and indicator results for all the impacts of 1MT of paddy harvested. Interestingly, although all impact categories were selected for analysis, only seven of the fourteen categories showed impact potential and these include the global warming, acidification, eutrophication, photochemical oxidant, solid waste, resource consumption and fossil energy resource consumption. Also, the top three significant impacts are the fossil energy resource consumption (1715 MJ), global warming (298 kg CO2 equivalent) and eutrophication (29.3 kg PO4 equivalent). Meanwhile, the other impacts are much smaller in comparison to the top three. The top three impacts will be discussed individually hereafter.

Table 2 Characterization results of environmental impact assessment of 1MT of paddy harvested using LIME

Impact Category	Characterization model	Indicator result
Global warming	IPCC-100 years (2001)	2.980E+02
Ozone depletion	WMO 1998	
Human toxicity (carcinogenicity)	HTP_cancer	
Human toxicity (chronic disease)	HTP_chronic disease	
Aquatic ecotoxicity	AETP	
Terrestrial ecotoxicity	TETP	
Acidification	DAP	1.800E-01
Eutrophication	EPMC	2.930E+01
Photochemical oxidant	OEFC	2.389E-03
Solid waste	m^3	6.305E-11
Land use (occupation)	m^2yr	
Land use (transformation)	m^2	
Resource consumption	1/R(Sb base)	5.647E-04
Fossil energy resource consumption	MJ	1.715E+03

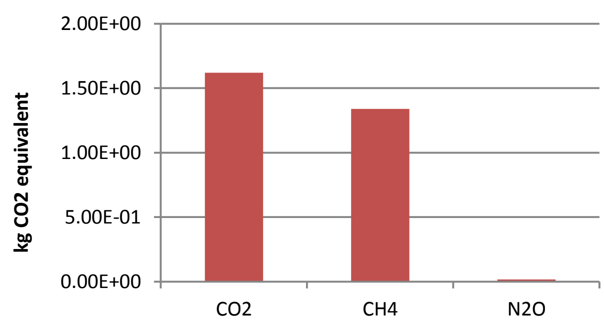


Fig.4 Contributors to the Global Warming Potential (GWP) for 1MT of paddy harvested

The global warming potential uses characterization factors from the International Panel of Climate Change for a time frame of 100 years. The contributions from various substances that contribute to climate change are calculated with respect to an equivalent substance which is CO_2. Figure 4 shows the two main contributors to climate change are CO_2 (54.3%) and CH_4 (45%). Reasons for this will be discussed in interpretation.

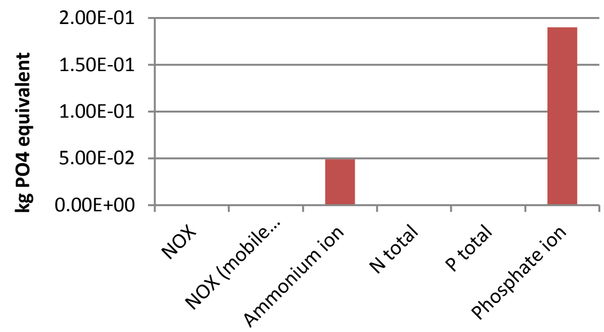


Fig. 5 Contributors to the Eutrophication Potential (EP) for 1MT of paddy harvested

Eutrophication is a process where algal bloom, due to the presence of certain nutrients, affects aquatic life. Phosphates and nitrates (present in most crop fertilizers) seep into groundwater via plant watering activities or rain and end up in lakes and rivers (Slack et al., 2005). These nutrients fertilize algae in lakes and rivers. When algae reproduce too quickly, they put away large quantities of oxygen. Shortage of oxygen in turn chokes other living things. Also, these algae block sunlight and prevent aquatic plants from performing photosynthesis. Sometimes, aquatic life may even be poisoned by the toxins in the algae. The eutrophication potential is measured using phosphate ion ($PO4^{3-}$) equivalence. All releases of nutrients into soil, water and air are included in these calculations. Figure 5 shows the top two contributors to eutrophication are the phosphate ions (79.5%) and the ammonium ions (20.5%).

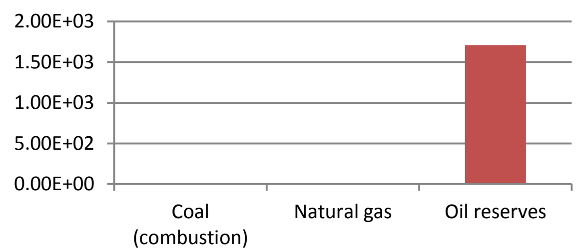
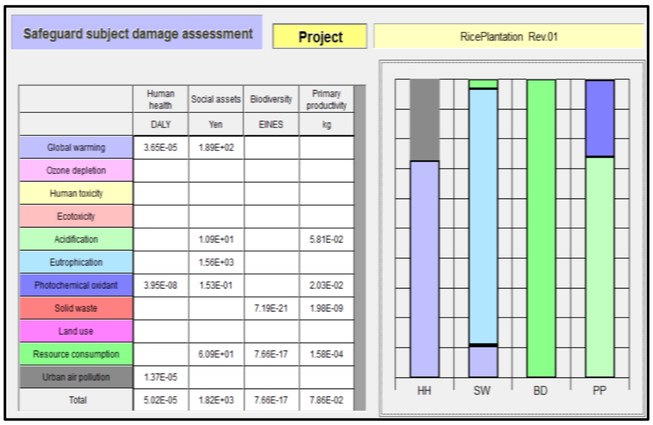


Fig. 6 Contributors to Fossil Energy Resource Consumption for 1MT of paddy harvested

Figure 6 shows that the greatest consumption in terms of fossil energy use is from the oil reserves. As mentioned earlier, this is due to use of machineries during the land preparation and harvesting processes as well as transportation of fertilizers and pesticides from suppliers to the farm and transportation of harvested grains to the mill. Total fossil energy consumption 1MT of paddy harvested is approximately 1700 MJ of energy.

Damage Assessment Following the characterization analysis, damage assessment was performed to observe how the impacts can cause total damage to the environment in terms four different end points; human health, social assets, biodiversity and primal productivity. Damage to human health is straightforward and looks at how the substances released into the environment can adversely affect human health by reducing the number of years lived. The unit used is Disability Adjusted Life Year or DALY. Social assets look into the damage from an economic standpoint (measured in Yen thus again reflecting a Japanese scenario in this case) where impacts on various components such as agricultural products, forests, marine products, and resources are measured in terms of loss. The biodiversity end point looks at the loss of species or risk of extinction. And finally, the primary productivity is an index indicating the richness of the ecosystem (JLCA, 2012). Figure7 shows the damage assessment results. It reinforces the findings from characterization where global warming, eutrophication, resource consumption remain as top impact categories as well as acidification.



	Human health	Social assets	Biodiversity	Primary productivity
	DALY	Yen	EINES	kg
Global warming	3.65E-05	1.89E+02		
Ozone depletion				
Human toxicity				
Ecotoxicity				
Acidification		1.09E+01		5.81E-02
Eutrophication		1.56E+03		
Photochemical oxidant	3.95E-08	1.53E-01		2.03E-02
Solid waste			7.19E-21	1.98E-09
Land use				
Resource consumption		6.09E+01	7.66E-17	1.58E-04
Urban air pollution	1.37E-05			
Total	5.02E-05	1.82E+03	7.66E-17	7.86E-02

Fig.7 Damage assessment results of the environmental impacts of 1MT of paddy harvested

3.3 Interpretation and sensitivity analysis

From the findings derived using JEMAI LCA Pro software, the three most significant potential environmental impacts of rice production in the chosen paddy field in Kedah are in the following order; fossil energy consumption, global warming and eutrophication. Based on the results derived from the LCIA phase, it appears that the high usage of fertilizers during the paddy cultivation stage had the most significant effect on all impact categories. As explained in the life cycle inventory analysis, the microbial degradation process of the fertilizers leads to a significant release of nitrogenous compounds ammonium and phosphate ions as well as greenhouse gases, CO_2 and CH_4, among other substances. With such high use of fertilizers, these substances are released in large quantities and hence, are the main perpetrators of eutrophication and global warming, explaining why these impacts are far more prominent than any other (Wang et al., 2010). On the other hand, the quantities of the pesticides used were so small, especially when compared to the amount of fertilizers used, and thus believed to have not caused much change to the impact indication results; albeit six different pesticides with various chemical components were used.

Average fertiliser application amounts recommended by Malaysian Agricultural Research and Development Institute (MARDI) are Urea – 94.1 kg/ha, Compound – 156.5 kg/ha and others – 48.9 kg/ha (Haque, Huang & Lee, 2010). However, this particular paddy farm has been using on an average; Urea – 110 kg/ha, Compound – 260 kg/ha and NPK – 148 kg/ha. This clearly indicates that the excessive use of fertilizers led to high potential impacts in eutrophication and global warming. Ironically, studies show that these very impacts do not just directly harm the environment; they also adversely impact the rice production process. The impacts cause degradation in water quality, soil fertility and this reduces yield which then increases food insecurity (Haque, Huang & Lee, 2010) (Siwar, Idris, Yasar & Morshed, 2014). Therefore, the very act of using fertilizers to enrich the soil for higher quality and yield may very well do the exact opposite. A conversation with the farm owner revealed that they were unaware on the optimum quantity to use; they simply used all that was given to them by the subsidising government body, MADA.

Another point to note is that the fossil energy resource consumption was the highest of all impact categories. This is mainly due to use of diesel in the machineries used during land preparation and the harvesting stage as well as in the vehicles used to transport the fertilizers to the paddy farm and the harvested grains to the mills. Although the distance between the suppliers, the farm and the mill are less than 15km between destinations, the readings are still relatively high. Seeing as how fossil fuel use is highly discouraged these days, this could be a reason why the characterization factor for this category is set to be high. Again these results are to be treated with caution for the calculations are all based on Japanese data and so reflect their environmental preferences better than our local scenario. Having said that, there is always room for improvement and one way is to perhaps look into other forms of more environmentally friendly fuel or to regularly service the machineries and vehicles for improved performance.

Sensitivity analysis The new LIME assessment chart, as seen in Table 3, showed the presence of new potential impacts which is human toxicity and ecotoxicity. Terrestrial and aquatic ecotoxicity impacts gave higher indicator results (338.7 C6H6 soil eq. kg and 49.71 C6H6 water eq. kg) compared to human toxicity (5.281 C6H6 air eq. kg for HTP cancer and 0.005379 C6H6 air eq. kg for HTP chronic disease). This is may be due to inclusion of heavy metals which are modelled as long-term emissions producing higher toxicity impacts over the longer time horizons. According to Guo (2012), higher impact scores in ecotoxicity results are due to the significant uncertainties, which in this study include the unknown quantity of inert ingredients in the pesticides and thus the heavy metal emissions. As mentioned earlier, the unknown chemical make-up of the pesticides led to need of the cut-off criteria made to further execute this LCA study. This inadvertently may have caused several potential impact categories to be missed as what is now seen in the sensitivity analysis.

Table 3 LIME Characterization after Sensitivity Analysis

Impact Category	Characterization model	Indicator result
Global warming	IPCC-100 years (2001)	3.083E+02

Ozone depletion	WMO 1998	
Human toxicity (carcinogenicity)	HTP_cancer	5.281E+00
Human toxicity (chronic disease)	HTP_chronic disease	5.379E-03
Aquatic ecotoxicity	AETP	4.971E+01
Terrestrial ecotoxicity	TETP	3.387E+02
Acidification	DAP	1.275E-01
Eutrophication	EPMC	8.437E+00
Photochemical oxidant	OEFC	2.389E-03
Solid waste	m^3	6.296E-11
Land use (occupation)	m^2yr	
Land use (transformation)	m^2	
Resource consumption	1/R(Sb base)	5.653E-04
Fossil energy resource consumption	MJ	1.717E+03

Table 4 Single index aggregated (Weighted) results after Sensitivity Analysis using LIME

	Item	LCI result	Unit	Points
water	ammonium ion	2.65E+01	kg	8.47E+02
water	N total	1.18E+01	kg	4.86E+02
air	CO2	1.63E+02	kg	2.11E+02
air	CH4	6.22E+00	kg	1.99E+02
soil	Cd	8.00E-05	kg	3.60E+01
air	PM10 (mobile source)	3.41E-03	kg	3.25E+01
resource	oil reserves	4.16E+01	kg	3.04E+01
soil	Pb	8.00E-05	kg	2.62E+01
air	SOx	2.52E-02	kg	2.28E+01
air	NOx (mobile source)	1.13E-01	kg	2.20E+01
soil	As	8.00E-05	kg	6.94E+00
air	NOx	2.72E-02	kg	3.96E+00
water	P total	6.00E-03	kg	2.91E+00
air	N2O	5.98E-03	kg	2.46E+00

Table 5 Eco-Indicator 95 Characterization after Sensitivity Analysis

Impact category	Indicator result	Characterization model	Unit
Greenhouse effect	2.28E+02	GWP	CO2 eq. kg
Ozone layer depletion		ODP	CFC eq. kg
Acidification	1.77E-01	AP	SO2 eq. kg
Eutrophication	2.70E+01	NP	Phosphate eq. kg
Summer smog	4.30E-02	POCP	ethene eq. kg
Winter smog	6.70E-02	1 / EQS	SO2 eq. kg
Pesticides	1.00E-01	-	kg
Heavy metals		1 / EQS	Pb eq. kg
Carcinogenics		1 / EQS	PAH eq. kg

However, the weighted results (Table 4) shows that these impact contributions are very small compared to the initially identified major contributors to environmental impact of rice cultivation, the ammonium ions, N total, CO_2 and CH_4, all of which arise from the excessive use of fertilizers. Therefore, it is possible to conclude that the LCA findings still stand but the results must be treated with caution. Coincidentally, LCIA using Eco-Indicator 95 (Table 5) did not show any new potential impacts in impacts category of heavy metals & carcinogen; this could be due to very small contributions.

Limitations In this LCA study on paddy cultivation, a variety of limitations and obstacles were met with, which are explained in detail as follows:

i) Data gaps: Lack of data for chemical inputs and emissions data as well as unreliability of some data forced a fair amount of estimation to be done, which had some effect on the final environmental impact assessment.
ii) Poor access to data: This study relied a lot on purchase receipts of chemicals such as fertilizers and pesticides and energy, water bills to calculate the inputs into the system. This led to the use of secondary data such as material safety data sheets (MSDS) to help with estimation.
iii) Trade secrets: The pesticide and fertilizers manufacturers or distribution companies were contacted to obtain the ingredients in said chemical products. However, there was no cooperation due to company trade secrets which made work more difficult due to different ingredients and the volume percentages in those chemicals.
iv) Uncertain fate and transport of the chemicals: JEMAI LCA Pro software did not have databases for most of the unique chemicals found in the pesticides and fertilizers, therefore it was necessary to enter them manually to the software. Ideally, it would be best to perform field measurements or some laboratorial research to identify and quantify the emissions from the various unique chemical inputs. This is however a resource, labour and time intensive approach, and so secondary data such scientific journals were used instead. Unfortunately, accurate information on fate and transport of the said unique chemicals in the environment are not vastly available leading to a fair amount of estimation and assumptions.
v) Time constraint: In an actual LCA study on rice farming, it is crucial to collect data from more than one paddy field and if possible, for more than one season to collect all input data accurately.
vi) Lack of a national database, specifically for rice production: Various other studies that have been conducted for the same rice farming process in countries like Japan or Thailand used their national databases to calculate the emissions of rice farming. Since there is a lack of access to such a national database here in Malaysia, the results obtained may not represent accurate potential impacts in a Malaysian context and so must be treated with caution.

3.4 Extrapolation of Farm-level Data to Regional-level Data

The extrapolation has been limited to Peninsular Malaysia mainly due to the fact that most low-lying or more commonly known as wetland paddy fields are concentrated in this region. By limiting the geographical scope to this region, it warrants uniformity in cultivation practices and environmental conditions. The results from the LIME characterization has been chosen to represent local scenario best. Based on the statistics provided by the Department of Agriculture (2014), the overall yield of wetland paddy for Peninsular Malaysia in 2011 is 903 674 metric tonnes whereas the farm's yield is 9.26 metric tonnes. This yield ratio provides a multiplying index in the extrapolation calculation. Using Equation 6 and the method prescribed in 2.4, the regional level impact potentials have been calculated and presented in table 6.

Table 6 Extrapolation Results

Type of Impact	Farm Level	Regional Level
Eutrophication Potential ($kg\ PO_4$ eq./1MT paddy)	29.3	2 859 357
Global Warming Potential ($kg\ CO_2$ eq./1MT paddy)	298	29 081 517

Results from table 6 show a huge hike in the impact potential values after extrapolation from farm-level to regional-level. The regional level values represent the sum of the impact potential from the various farms scattered around the Peninsular Malaysia that collectively produced 903 674 metric tonnes of paddy grains in 2011. As mentioned before, this exercise was done to drive home the idea that rice farming could at large cause catastrophic impacts to the region is the farms continue to practice the same farming techniques as they do now. 2.8 million kg of phosphate equivalent pollutants and 29 million kg of carbon dioxide equivalent global warming agents is only per one metric tonne of paddy grain produced. If this value was up scaled for the total yield of Peninsular Malaysia in 2011, the resulting value is in the trillions which are alarming. An article published in 2009 by Allen et al. states that 3.67 trillion tonnes of CO_2 could cause an induced warming of 2ºC which is dangerous to the eco system.

The results from the extrapolation are simply a gross estimation to illustrate the potential dangers of the current cultivation practices. Though far from accurate, it acts as a precursor to summon for more local LCA research into the rice farming practices of wetland paddy, which is expected to intensify in order to achieve Malaysia's goal of self-sustenance. If left unchecked, the damage may be too great and it might be too late before action is taken.

4 Conclusions

Following the LCA analysis and the extrapolation exercise conducted to estimate the environmental impact of paddy cultivation in Malaysia, this study concludes that the greatest impacts in the paddy cultivation stage of rice production global warming and eutrophication. The detailed conclusions are as follows:

i. From the LCA analysis, the LIME method of impact assessment quantifies the global warming impact potential as 298 kg CO_2 eq./1MT paddy and the eutrophication potential as 29.3 kg PO_4 eq./1MT paddy. A third environmental impact was also identified, which is the fossil fuel resource consumption (1715MJ per 1MT of paddy grain harvested). Previous studies conducted on paddy cultivation corroborate these findings with the eutrophication and global warming potential being the impact potentials of greatest concern (Fusi et al., 2014; Wang, Xia, Zhang, & Liu, 2010).

ii. The extrapolation results for the impacts highlighted above are global warming potential of 29 million kg CO_2 eq./1MT paddy and eutrophication potential of 2.8 million kg PO_4 eq./1MT paddy. This shows that collectively, farms in the Peninsular Malaysia, which on the whole employ the similar cultivation practices, potentially contribute vast amounts of GHG and nitrogenous compounds to the regional eco system. The nutrition management during the paddy cultivation stage must improve for eutrophication and global warming are impacts that bring harm regionally and globally.

iii. The quantity of fertilizers used by the chosen paddy farm in the case study is exorbitant (more than 60% in excess of what is the recommended quantity (Haque, Huang & Lee, 2010)) and must be looked into for it is the leading cause of the eutrophication and global warming potentials. Following a discussion with the farm operators, it is evident that they do not seem know what appropriate amount to use is; they make use of all the fertilizers provided to them under the MADA subsidy.

iv. The pesticides used by the chosen farm in this case study were in very small quantities as compared to the fertilizers; 21kg of pesticides versus 1867kg of fertilizers. Hence, no grave adverse effects were detected. However, results are to be treated with caution as information on all inert ingredients could not be obtained due to trade secrets and so the presence of harmful solvents or heavy metals could not be proved despite literature proving its presence. The results from the sensitivity analysis validate these findings.

v. The findings from this study find the paddy cultivation process to be a major environmental hot spot. In line with the country's goal to become self-sufficient producers of rice, future LCA studies on rice production (specifically paddy cultivation and its nutritional management stage) must be conducted complete with field managements to better assess and quantify the environmental impacts in order to obtain concrete recommendations or alternatives for nutrient management.

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