

LIFE CYCLE ASSESSMENT OF THE STRAW MUSHROOM PRODUCTION

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Abstract. The life cycle assessment of a product (LCA) is a tool to calculate the quantity of environmental emissions from each production unit throughout the whole life cycle of a specific product starting from raw material extraction, manufacturing, use and distribution to the final disposal. This tool becomes increasingly more necessary to consumers as information pertaining to environmental impacts which partially supports their purchasing decisions in Thailand. Therefore, the objective of this study is to analyze the environmental impacts of SMEs straw mushroom production with three different formulas including the soybean hull formula, rapeseed hull formula and the cassava peel formula. The functional unit was set at 1 kg of the straw mushroom at the farm gate. The inventory data was collected from a farm in Nakornsawan province, Thailand. The environmental impacts were dominated by global warming, eutrophication and acidification. Results were compared with environmental impacts of a straw mushroom production by using the rapeseed hull formula and the cassava peel formula with a soybean hull as the conventional method. Results indicated that the straw mushroom production with a cassava peel had the lowest environmental impacts. The comparison in terms of global warming impact of three formulas were 1.6 kgCO₂e for the soybean hull formula, 5.4 kgCO₂e for the rapeseed hull formula and 0.8 kgCO₂e for the cassava peel formula. The acidification impact of the soybean hull, cassava peel and the rapeseed hull were revealed at 13.5 gSO₂e, 8.3 gSO₂e and 23.9 gSO₂e, respectively. The eutrophication impact of the soybean hull, cassava peel and the rapeseed hull were 10.0 gPO₄³⁻e, 1.9 gPO₄³⁻e and 42.5 gPO₄³⁻e, respectively. Uncertainty analysis of production yield, fungi yield, types of cotton production and types of plastic used were evaluated. The result showed that the organic farming of cotton production could reduce environmental impacts of straw mushroom production.

Keywords: *Volvariella volvacea, global warming, eutrophication, acidification, life cycle impact assessment*

Introduction

The mushroom is the fruiting body of a macro-fungi (Chang and Milles, 1991). The world production of mushrooms were 7.96 million tons in 2012 (FAOSTAT, 2012). China, as the largest mushroom producing country in the world, produced 5.15 million tons alone. For Thailand, mushroom production was 6,820 tons in 2012 (FAOSTAT, 2012). In 2012, agricultural products accounted for 12.3% of Thailand's gross domestic product (GDP) (OAE, 2013)

The straw mushroom is a kind of mushrooms that is preferred by most consumers because of its aroma and taste (Tharun, 1993). Straw mushrooms, scientifically known as *Volvariella volvacea*, is a type of mushroom abundantly found throughout Asia. Paddy straw is the most common substrate for this mushroom. Nowadays, it is popular among consumers because of its distinct flavor, pleasant taste, higher protein content and shorter cropping duration (Rajapakse, 2011). Straw mushrooms can be used as an ingredient in a vast variety of Thai recipes, such as stir-fried pork with oyster sauce, spicy soup with prawn and lemon grass or chicken Tom Yum.

New trends in the environment, economy and society have been growing and is a concern when dealing with current non-sustainable developments. These factors have led to an increased interest in the life cycle assessment (LCA) as it is a tool used to evaluate the environmental impacts of products, services or processes. Food, one of the primary needs of human beings, creates an environmental impacts in each phase of its life cycle. In Thailand, there has been a concern in the food industrial sector regarding the significant impact to global warming.

Several researchers have studied many aspects about the straw mushroom such as the techniques for its cultivation for which cotton waste and paddy straw are used (Rajakakse, 2011). The cultivation of the straw mushroom has been tested with various agricultural by-products such as banana leaves, sawdust, rice bran, wheat bran, sugarcane bagasse, wheat and rice straw. However, straw alone is not sufficient as a composting material as it contains little in the quantity of nutrients (Anon, 1983). There are a few publications related to the LCA calculation of mushrooms. The LCA of the sajour-caju mushroom was determined and evaluated from three farm sizes (Ueawiwatsakul et al., 2014). Gunady et al. (2012) determined the LCA from strawberries, lettuces and button mushrooms in Western Australia. However, none of these studies have been specified in the LCA of straw mushrooms or even in Thailand.

Therefore, the main objective in this study was to analyze three environmental impacts including the potential of global warming, acidification and eutrophication. In addition, the sub-objectives were 1) to compare three different cultivation formulas; soybean hull, cassava peel and rapeseed hull formulas, 2) to identify emission hotspots with the highest amount of environmental impacts and 3) to evaluate the uncertainties of core factors related to the cultivation process.

Materials and Methods

Methods of commercial mushroom cultivation generally involve inoculating beds of composts with mushroom spawn. Such compost is rich in nutrients and capable of supporting the mushroom fruiting stage (Romaine and Marlowe, 1995). The addition of protein-rich, lipid-rich supplements such as soybean meal to the compost has become a widespread practice in the commercial cultivation of the button mushroom (Romaine and Marlowe, 1995).

According to the guidelines in ISO14040 (2006), LCA consists of four phases namely: 1) goal and scope definition that includes the functional unit and system boundary 2) inventory analysis of inputs and outputs of the selected boundary 3) environmental impact assessment classifying the collected data into impact categories and 4) interpretation which leads to the conclusions and verifications.

Goal and scope definition

The main purpose of this study was to analyze three environmental impacts in terms of global warming, eutrophication and acidification of straw mushroom production with different formulas. The LCA was utilized as the tool to analyze these impacts in this study. The classification and characterization method of CML based line 2001 was also applied. Three scenarios (case 1 to case 3) were considered depending on the main raw materials used for cultivation process. A soybean hull, cassava peel and rapeseed hull were used as the raw materials for case 1, case 2 and case 3, respectively. The sub objectives were 1) to compare three different cultivation systems; soybean hull, cassava

peel and rapeseed hull formulas 2) to identify the hotspots at which the inputs emit the highest amount of environmental impacts and 3) to evaluate uncertainties of core factors related to the cultivation process. Based on this study, the research questions can be summarized as 1) What are the environmental impacts of the straw mushroom in each scenario? 2) What are the main hotspots associated with straw mushroom production? 3) What are the important factors related to the uncertainty of the results of this study?

System boundary

The straw mushroom was cultivated on shelves of grow bags in plant houses with rows of shelves inside. These houses are tolerant to subsequent, severe heat treatment during on-sight pasteurization (Kwon and Thatithatgoon, 2004). The cultivation phase in this study began with marinating cotton and cow manure for one night. In addition to that, soaked rice bran, lime, gypsum, urea fertilizer and compressed rice straw together in water for one night was also used. Subsequently, all were placed in a row and materials steamed at 80 degree Celsius for three hours as per the pasteurization procedure. Lastly, the mushroom spores were spread in grow bags under the conditioned ambient at temperatures of 32-38 degree Celsius for twenty days until time of harvest.

The selected farm is located in Nakornsawan province in the central part of Thailand. This system boundary included raw materials used in this straw mushroom production such as soybean hull, cassava peel, rapeseed hull, urea, rice straw as well as other materials, and the production of the straw mushroom in the so called “cradle-to-farm gate”. The pre-farm stage included emissions from fertilizer production, chemical production, electricity, gypsum production, lime production, cotton production, wood chip and plastic bag. The on-farm stage included fertilizer use, electricity consumption, chemical uses as well as both direct and indirect N₂O emissions from N-fertilizer applications. However, the production of capital goods from the system boundary and transportation of all raw materials were excluded. In addition, the product system excluded solid waste from cultivation.

Functional unit

The activity data of both input and output, and the environmental impact are related to the functional unit. The functional unit is defined as a quantitative reference to which inputs and outputs are related to the selected boundary. It is one of the keys in the LCA, facilitating the comparison of alternative products and services (ISO14040, 2006). In this study, the functional unit of this study was defined as 1 kg of straw mushroom produced in Thailand.

Results and discussion

Life cycle inventory

In the inventory phase, all data required to analyze the environmental impacts associated with the functional unit were gathered. In this study, data was derived from various sources. Primary data was the first option in this step. A one year period of activity data on straw mushroom production was collected from a farm located in the central part of Thailand. Different cultivation methods were identified by using a life cycle inventory (LCI). For the assembly of the inventory, the foreground system was

considered based on the primary data from actual field operations during the cultivation process. However, the data associated with the effects as a result of the inputs such as fertilizer production, electricity, plastic production and chemicals production were obtained from a secondary data source such as the Thailand National LCI database and other literature sources.

Thailand possesses very suitable attributes for mushroom cultivation as there is a large number of left-over material and agricultural by-products from plants and animals that can be used for growing mushrooms (Thongnaitham, 2012). A variety of waste material used for general cultivation of straw mushrooms includes paddy straw, water hyacinth, oil palm bunch, banana leaves, saw dust, cotton or sugarcane bagasse. However, waste material used in this study included soybean hull, cassava peel and rapeseed hull and the average inventory with three formulas are shown in *Table 1*. Inventory values of material and energies used for producing 1 kg of straw mushroom. Gypsum and lime are used to adjust the pH and provide mushrooms with calcium and magnesium (Thongnaitham, 2012).

Table 1. Inventory activity data of 1 kg straw mushroom

Inventory activity data	Value		
	Case 1 (soybean)	Case 2 (cassava)	Case 3 (rapeseed)
Soybean hull (kg)	1.4969	-	3.2550
Cassava peel (kg)	-	1.0396	-
Rapeseed hull (kg)	-	-	2.3508
Cow dung (kg)	0.0832	0.0578	0.1808
Cotton (kg)	0.4990	0.3465	1.0850
Rice bran (kg)	0.2495	0.1733	0.5425
Lime (kg)	0.0125	0.0087	0.0271
Gypsum (kg)	0.0166	0.0116	0.0362
Urea (kg)	0.0042	0.0029	0.0090
Straw (kg)	1.0811	0.7508	-
Fungi spawn (kg)	0.3400	0.2300	0.7324
Underground water (L)	43.2432	30.0335	94.0325
Wood chip (kg)	0.9979	0.6931	2.1700
Plastic bag (kg)	0.0064	0.0064	0.0064
Electricity (kWh)	0.0124	0.0086	0.0270

Emission factor

The emission factors for material and fuel production, fuel combustion, electricity generation, direct and indirect emission due to synthetic and organic fertilizers are listed in *Table 2*. Emission factors assessed in this study were taken from the Thailand National LCI database and international database. If available, Thailand specific emission factors were also used. The emission factor of the electricity grid mix was calculated based on Thailand's National LCI database. Emission factors resulted from rice bran and straw production were estimated from the LCI of rice production and allocated by mass (Kasmaprapruet et al., 2009). The mushroom spore is generally referred to as a spawn (Oei, 2005). In this study spawn production involved raw materials such as cow manure and soybean hull. Based on the interviews, to produce one kilogram of spawn, 0.32 kg cow manure and 0.66 kg soybean hull were used. Moreover, in terms of wood chip and cassava peel, production inventory data was also estimated from the primary data collected from rubber tree farmers and the cassava

industry respectively. In the case that no emission factors in Thailand were evident, international databases were then estimated from an ecoinvent database or other literatures. The direct N₂O emission factor was estimated to be 1% of applied N fertilizer both synthetic and organic fertilizer (IPCC, 2006). To estimate the impacts of organic fertilizer used in the process, the composition of cow manure must be known. The composition of nitrogen (N), phosphorous (P) and potassium (K) in cow manure are 0.57%, 0.15% and 1.22%, respectively (Akhtar et al., 2013). The indirect N₂O emission factor was assumed by calculating N-leaching and N-runoff (IPCC, 2006). Moreover, the CO₂ emission due to urea fertilizer and lime were determined to be 20% of applied urea and 12% of applied lime, respectively (IPCC, 2006).

Table 2. Emission factors for maternail productions including direct and indirect emissions

Material	Emission factor			Source
	GWP (kgCO ₂ e/unit)	AP (kgSO ₂ e/unit)	EP (kgPO ₄ ³⁻ e/unit)	
Soybean hull	2.69E-1	3.78E-3	2.89E-3	CML2001, Ecoinvent database
Cassava peel	8.41E-3	2.69E-3	2.40E-5	Field visited
Rapeseed hull	9.74E-1	5.83E-3	9.71E-4	Bernesson, 2004
Cow dung	3.51E-2	1.11E-3	2.48E-4	Calculated from manure management (IPCC, 2006)
Cotton	1.33E+0	1.16E-2	2.89E-3	Muruges and Selvadass, 2013
Rice bran	1.05E-1	1.86E-4	2.18E-5	Calculated from Kasmaprapruet et al, 2009
Lime	1.92E-3	3.38E-5	7.79E-6	CML2001, Ecoinvent database
Gypsum	2.03E-3	3.45E-5	7.92E-6	CML2001, Ecoinvent database
Urea	5.93E+0	1.62E-2	2.91E-3	CML2001, Ecoinvent database
Straw	1.26E-1	2.23E-4	2.62E-5	Calculated from Kasmaprapruet et al, 2009
Fungi spawn	1.89E-1	2.85E-3	3.27E-3	Field visited
Wood chip	2.05E-1	6.35E-4	1.29E-4	Field visited
Plastic bag	1.92E+0	6.57E-3	5.16E-4	CML2001, Ecoinvent database
Electricity	6.09E-1	7.26E-4	1.06E-4	Thailand National Database

Impact assessment

The impact assessment evaluates three impact categories: global warming potential, acidification potential and eutrophication potential based on the inventory analysis. The potential impact assessment was quantified by using classification and characterization factors of CML baseline 2001. The calculation of environmental impacts lied on the equation 1:

$$E_x = \sum_i (A_i \times EF_{x,i}) \quad (\text{Eq.1})$$

Where E_x is environmental impact x (index for impact category: global warming, acidification, eutrophication). A_i is the activity data in each of the cultivation process as shown in *Table 1*. EF_{x,i} stands for the emission factor for each impact category due to activity i in the cultivation process, as shown in *Table 2*.

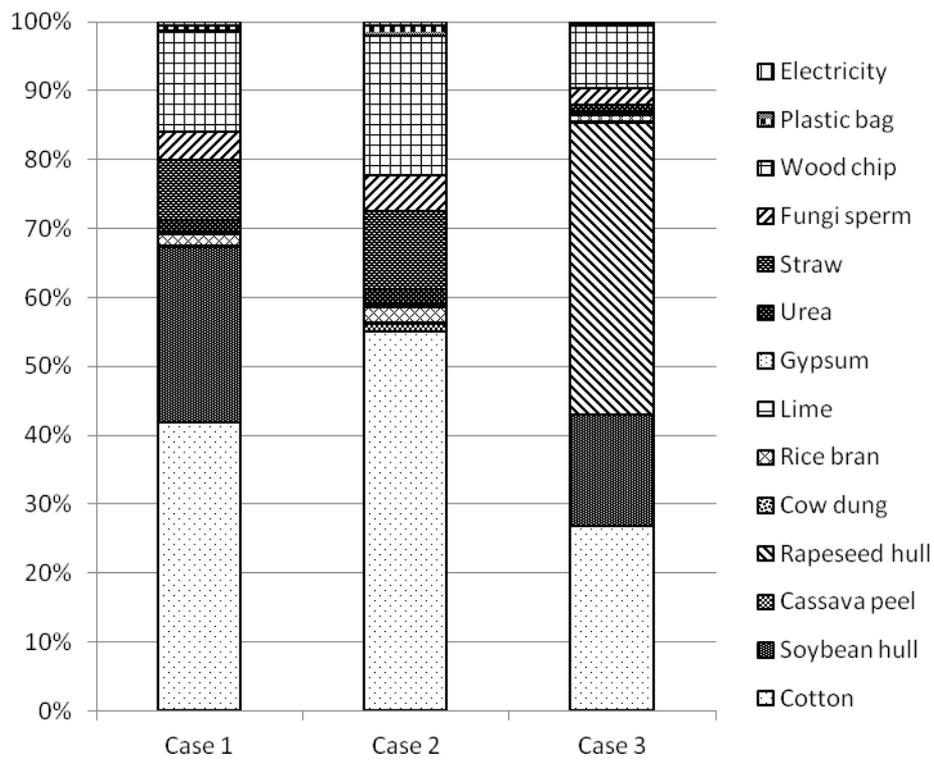
Table 3 illustrates 3 environmental impacts of 1 kg straw mushroom production in each case. The results reveal that case 2 is the lowest impact category compared to

others. In case 2, the equivalence of 0.8 kgCO₂e, 8.3 gSO₂e and 1.9 kgPO₄³⁻e are emitted as a result of the production of 1 kg of the straw mushroom. Case 1 as the conventional cultivation process emitted global warming potential, acidification potential and eutrophication potential that are higher than case 2 at 89%, 426% and 63%, respectively. Case 3 is the highest impact among three cases for several reasons. First, case 3 requires more raw materials such as cotton, rice bran and cow manure to produce 1 kg of straw mushroom. Second, case 3 uses soybean hull instead of straw when the emission factor of soybean hull is higher than that of rice straw.

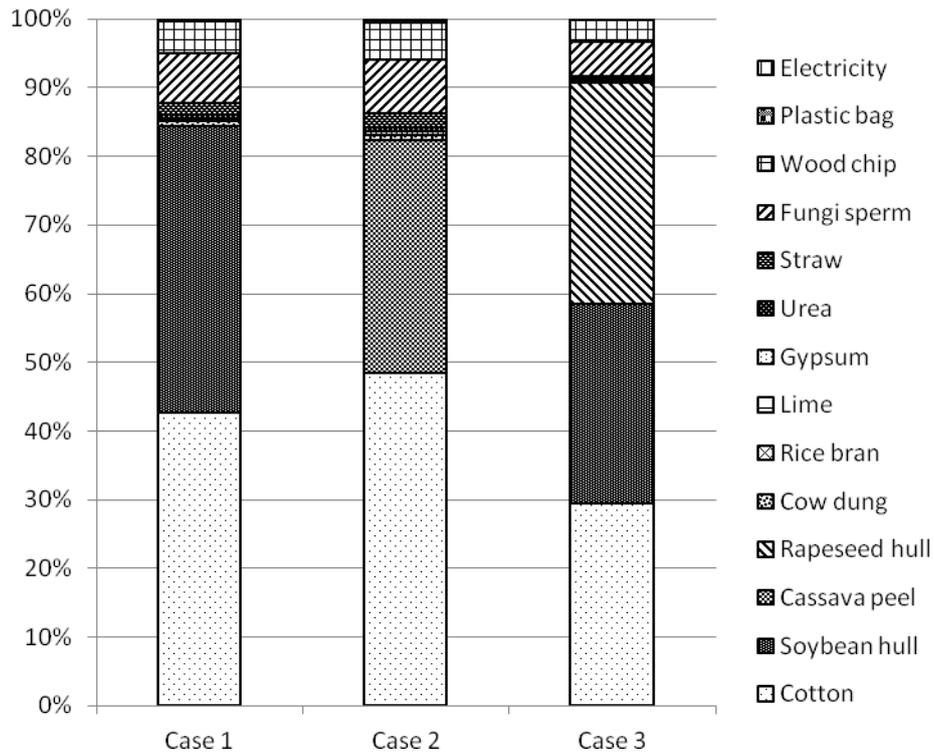
Table 3. Environmental impact of the production of 1 kg straw mushroom

Impact category	Unit	Case 1	Case 2	Case 3
Global warming	kg CO ₂ e	1.5837	0.8372	5.3973
Eutrophication	kg PO ₄ ³⁻ e	0.0100	0.0019	0.0425
Acidification	kg SO ₂ e	0.0135	0.0083	0.0239

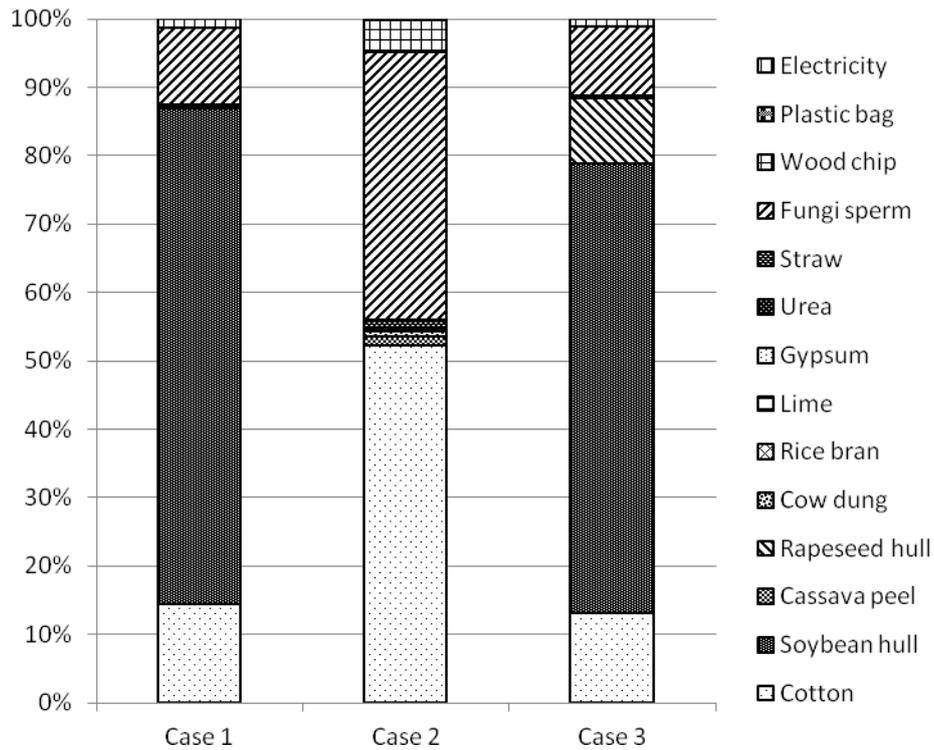
For better understanding of these results, the breakdown of contributions to the environmental impacts are performed. *Figure 1* illustrates the percentage contribution of three environmental impact categories from different cases. In case 1, the hotspot of global warming potential, acidification potential and eutrophication potential are cotton production (42%), cotton production (43%) and soybean hull (72%), respectively. The main factor to global warming potential caused by cotton production is the use of plant protecting chemicals like pesticides, herbicides and synthetic fertilizers (Muruges and Selvadass, 2013). The soybean hull and wood chip are shown to be the second and the third contributors to the global warming impact.



(a) Global warming contribution



(b) Acidification contribution



(c) Eutrophication contribution

Figure 1. Contribution of activities in the environmental impacts of 1 kg straw mushroom production

Electricity and use of fertilizers does not seem to have significant impact potentials. The contribution of electricity and fertilizers on the global warming potential are only less than 1% and 2%, respectively. In case 2, cotton production has been identified as the hotspot of all impact categories. The global warming potential, acidification potential and eutrophication potential of case 2 related to cotton production are 55%, 48% and 52% of total impact categories respectively. The production and combustion of wood chip and straw production are shown to be the second and the third contributors to global warming. In case 3, the hotspot of global warming potential and acidification are rapeseed production; 42% and 32%, respectively. However, the hotspot of eutrophication in case 3 is soybean hull (66%). From the *Figure 1*, it is clear that cotton production is an important source of pollutants and their environmental impacts, followed by rapeseed hull and soybean hull production.

Uncertainty analysis

Uncertainty analysis is one of the necessary parts of the analysis model. It is used in order to test the robustness of conclusions to uncertainties in assumptions (Sterman, 2000). In this study, an uncertainty analysis was assumed to identify the effect of some possible changes on the straw mushroom cultivation. Six scenarios were considered in this uncertainty analysis: (1) straw mushroom yield has been increased by 10%, (2) straw mushroom yield has been decreased by 10%, (3) fungi spawn yield has been increased by 10%, (4) fungi spawn yield has been reduced by 10%, (5) cotton cultivation has been changed to organic farming (6) HDPE plastic has been switched to biodegradable plastic (*Table 4*). The results of this uncertainty analysis are compared to the base case.

Table 4. Variables changed in sensitivity analysis

Variable	Base case	Assumption changed
Straw mushroom yield	1 kg of straw mushroom (Data from <i>Table 1</i>)	Decrease and increase by 10%
Fungi spawn yield	1 kg of fungi spawn production	Decrease and increase by 10%
Cotton cultivation	Synthetic fertilizer	Organic fertilizer
HDPE plastic	HDPE	Sugarcane-based biodegradable plastic

As shown in *Table 5*, the uncertainty values ranging between -20.02% to 11.11% have a significant impact on the final results. Based on this observation, straw mushroom yield and type of cotton cultivation posts a significant effect to environmental impact results. A 10% increase in straw mushroom yield results at the range of 8.89% to 9.09% decreases from base case, whereas a 10% decrease in straw mushroom yield results at the range 10.98% to 11.11% increases from base case. In contrast, increasing fungi spawn yield results in only 0.23% to 3.56% decreases from base case. For scenario 4, in the event that fungi spawn yield decreases to 10%, this has a negative effect on the environmental impact up to 4.35%. For scenario 5, if organic cotton cultivation is used to replace synthetic cotton cultivation, this has a positive effect on the environmental impact up to 20.02% of acidification potential in case 2. For scenario 6, providing that biodegradable plastic is used to replace HDPE plastic bags, it is found that the impact results at the range of -1.09% to 1.12% different from base

case. Therefore, it is interesting that fungi spawn yield and types of plastic bags do not seem to have significant impacts.

Table 5. *Unvertainty analysis of factors related to straw mushroom production in term of % difference*

	Case 1			Case 2			Case 3		
	GWP	AP	EP	GWP	AP	EP	GWP	AP	EP
Scenario1	-8.98%	-9.09%	-9.09%	-8.89%	-9.09%	-9.09%	-9.06%	-9.09%	-9.09%
Scenario2	10.98%	11.11%	11.11%	10.86%	11.11%	11.11%	11.07%	11.11%	11.11%
Scenario3	-0.37%	-0.65%	-1.01%	-0.47%	-0.722%	-3.56%	-0.23%	-0.45%	-0.91%
Scenario4	0.45%	0.79%	1.24%	0.58%	0.88%	4.35%	0.29%	0.55%	1.11%
Scenario5	-7.84%	-17.60%	-4.72%	-10.30%	-20.02%	-17.05%	-5.01%	-12.17%	-4.29%
Scenario6	-0.57%	0.68%	0.00%	-1.09%	1.12%	1.49%	-0.17%	0.22%	0.12%

The mushroom yield is a factor that varies in environmental impacts, as shown in *Table 5*. However, these values have no effect to evaluate in percentage in terms of contributions as shown in *Table 5* that results of scenario 1-4 are at the same percentile. From *Table 5* and *Table 6*, it is obvious that cotton production is an important source of environmental impacts. In case 1, cotton production has the largest share in global warming (42%), acidification (43%) and eutrophication (14%). In case 2, cotton production also has the largest share in global warming (55%), acidification (48%) and eutrophication (52%). In case 3, rapeseed hull has the largest share in global warming (42%), acidification (32%) and eutrophication (10%).

Table 6. *Percent contribution of environmental impacts of scenario 1-4*

	Case 1			Case 2			Case 3		
	GWP	AP	EP	GWP	AP	EP	GWP	AP	EP
Cotton	42%	43%	14%	55%	48%	52%	27%	29%	13%
Soybean hull	25%	42%	72%	0%	0%	0%	16%	29%	66%
Cassava peel	0%	0%	0%	1%	34%	1%	0%	0%	0%
Rapeseed hull	0%	0%	0%	0%	0%	0%	42%	32%	10%
Cow dung	2%	1%	0%	0%	1%	1%	0%	0%	0%
Rice bran	0%	0%	0%	2%	0%	0%	1%	0%	0%
Lime	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gypsum	2%	0%	0%	0%	0%	0%	0%	0%	0%
Urea	10%	1%	0%	3%	1%	0%	1%	0%	0%
Straw	4%	2%	0%	11%	2%	1%	0%	0%	0%
Fungi spawn	15%	7%	11%	5%	8%	39%	3%	5%	10%
Wood chip	1%	5%	1%	20%	5%	5%	9%	3%	1%
Plastic bag	0%	0%	0%	1%	1%	0%	0%	0%	0%
Electricity	0%	0%	0%	1%	0%	0%	0%	0%	0%

The cotton used in this investigation has global warming potential in case 1, case 2 and case 3 of 0.66 kgCO₂e per kg of straw mushroom, 0.46 kgCO₂e per kg of straw mushroom and 1.44 kgCO₂e per kg of straw mushroom respectively. As mentioned

earlier, cotton production is a quantitatively important factor that contribute to global warming potential with 42% in case 1, 55% in case 2 and 27% in case 3. The synthetic cotton cultivation had a global warming potential of 1.33 kgCO₂e per kg of cotton, acidification potential of 1.16E-2 kgSO₂e per kg of cotton and 2.89E-3 kgPO₄³⁻e per kg of cotton (Muruges and Selvadass, 2013). However, based on Muruges and Selvadass (2013) if organic cotton were used instead, the global warming potential, acidification potential and eutrophication potential would be reduced by 19%, 41% and 33% respectively. Therefore, the contribution of environmental impact due to the change of cotton cultivation is demonstrated in *Table 7*. It is found that the change in cotton cultivation seems to have a significant influence to all impacts. The contribution of cotton cultivation to global warming potential of case 1, case 2 and case 3 are 37%, 50% and 23% respectively.

Table 7. Percent contribution of environmental impacts of scenario 5

	Case 1			Case 2			Case 3		
	GWP	AP	EP	GWP	AP	EP	GWP	AP	EP
Cotton	37%	30%	10%	50%	36%	42%	23%	20%	9%
Soybean hull	28%	51%	76%	0%	0%	0%	17%	33%	69%
Cassava peel	0%	0%	0%	1%	42%	2%	0%	0%	0%
Rapeseed hull	0%	0%	0%	0%	0%	0%	45%	37%	10%
Cow dung	0%	1%	0%	0%	1%	1%	0%	1%	0%
Rice bran	2%	0%	0%	2%	0%	0%	1%	0%	0%
Lime	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gypsum	0%	0%	0%	0%	0%	0%	0%	0%	0%
Urea	3%	1%	0%	3%	1%	1%	1%	0%	0%
Straw	9%	2%	0%	13%	3%	1%	0%	0%	0%
Fungi spawn	4%	9%	12%	6%	10%	47%	3%	6%	10%
Wood chip	16%	6%	1%	23%	7%	6%	10%	4%	1%
Plastic bag	1%	0%	0%	2%	1%	0%	0%	0%	0%
Electricity	1%	0%	0%	1%	0%	0%	0%	0%	0%

The HDPE plastic bag used in this investigation has a global warming potential of 1.92 kgCO₂e per kg HDPE, an acidification potential of 6.57E-3 kgSO₂e per kg HDPE and an eutrophication potential of 5.16E-4 kgPO₄³⁻e per kg HDPE. If sugarcane based biodegradable plastic were used instead, the environmental impacts would descent to 0.5 kgCO₂e per kg bioplastic for global warming potential, 0.021 kgSO₂e per kg bioplastic for acidification potential and 5.00E-3 kgPO₄³⁻e per kg bioplastic (Groot and Boren, 2010). Different contributors to the global warming potential, acidification potential and eutrophication potential are shown in *Table 7*. It was found that the change in the petroleum based plastic to biodegradable plastic caused reduction in global warming potential up to 1.09% of base case but increase in both acidification potential and eutrophication potential up to 1.49% of base case, as shown in *Table 5*. From *Table 8*, biodegradable plastic contributed from range 0% to 2% of total impacts. This means the change of plastic does not seem to have any significant influence among the three impacts.

Table 8. Percent contribution of environmental impacts of scenario 6

	Case 1			Case 2			Case 3		
	GWP	AP	EP	GWP	AP	EP	GWP	AP	EP
Cotton	42%	42%	14%	56%	48%	51%	27%	29%	13%
Soybean hull	26%	42%	72%	0%	0%	0%	16%	29%	66%
Cassava peel	0%	0%	0%	1%	34%	1%	0%	0%	0%
Rapeseed hull	0%	0%	0%	0%	0%	0%	42%	32%	10%
Cow dung	0%	1%	0%	0%	1%	1%	0%	0%	0%
Rice bran	2%	0%	0%	2%	0%	0%	1%	0%	0%
Lime	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gypsum	0%	0%	0%	0%	0%	0%	0%	0%	0%
Urea	3%	0%	0%	3%	1%	0%	2%	0%	0%
Straw	9%	2%	0%	11%	2%	1%	0%	0%	0%
Fungi spawn	4%	7%	11%	5%	8%	39%	3%	5%	10%
Wood chip	15%	5%	1%	20%	5%	5%	8%	3%	1%
Plastic bag	0%	1%	0%	0%	2%	2%	0%	0%	0%
Electricity	0%	0%	0%	1%	0%	0%	0%	0%	0%

Conclusion

Overall, the study has shown that the three environmental impacts namely; global warming potential, acidification potential and eutrophication potential of 1 kg of mushroom cultivation in Thailand for the best case that used the cassava formula were estimated using the LCA methodology to be 0.84 kgCO₂e, 8.3 gSO₂e and 1.9 gPO₄³⁻e, respectively. The hotspot was identified to be the production of cotton which accounts for 48% to 55% of total effects among three environmental impact categories. In the best case, electricity and fertilizers, however, played a negligible role. Moreover, it was observed that the results varied according to the production yield and types of cotton cultivation. The production yield increased or decreased by 10% affected environmental impacts by -9.09% to 11.11% compared to the base case. Organic cotton cultivation is highly recommended as environmental impacts could be reduced up to 20.02% of acidification impact compared to the base case. This study has also exhibited that raw materials such as cotton, soybean hull, cassava peel and rapeseed hull are the main impacts in the life cycle of straw mushroom production.

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