ENVIRONMENTAL ASSESSMENT OF PARBOILED PADDY PRODUCTION BY LIFE CYCLE ASSESSMENT

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DECLARATION

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Abstract

Rice is the most popular food in Sri Lanka where approximately 70% of the paddy production goes through the parboiling process. Parboiling process is a hydrothermal treatment method. This treatment process consumes energy, water and other environmental resources and adds air and solid emissions, effluents and wastages back to environment which cause adverse environmental impacts. Total environmental input and output emissions of the parboiling process depend on the selected treatment method and the type of equipment used. Therefore the total environmental effects of each and every step in the life cycle of the production process needs to be considered in order to identify the most environmental friendly paddy parboiling method.

The overall objective of this work is to assess environmental impacts of different parboiled paddy production methods adopted in Sri Lanka by using life cycle assessment (LCA) approach. LCA is a methodological context to estimate the environmental effects caused by the life cycle of a product, service or process. Goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation are the four major steps in LCA methodology.

The environmental performance of three parboiling methods named as modern method with hot soaking and mechanical drying, modern method with hot soaking and sun drying and semi modern method with cold soaking and sun drying were assessed and compared quantitatively and qualitatively. Processes from paddy harvesting to rice cooking are included in the system boundary.

According to the results, highest impact of parboiled rice production is given by the cooking step. The highest impacts from cold soaking operation method were observed in eutrophication, depletion of abiotic resources and climate change impact categories. The hot soaking method resulted highest impacts on human toxicity, photo oxidant formation and acidification.

Keywords:
Paddy parboiling, Life cycle analysis, Environmental Assessment

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LIST OF ABBREVIATIONS

Abbreviation	Description
BOD	Biological Oxygen Demand
CEB	Ceylon Electricity Board
CH_4	Methane
CO	CarbonMonoxide
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
GHG	Green House Gas
HC	Hydrocarbons
IPCC	Intergovernmental Panel on Climate Change
IQF	Individually Quick Frozen
ISO	International Organization for Standardization
KTN	Total Kjeldhal Nitrogen
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LPG	Liquefied Petroleum Gas
LSU	Louisiana State University
N_2O	Nitrous Oxide
NREL	National Renewable Energy Laboratory
NMHC	Non Methane Hydro Carbon
NMVOC	Non-Methane Volatile Organic Compounds
P	Phosphorous
PM	Particulate materials
PO_4^{-3}	Phosphate
RPRDC	Rice Processing Research and Development Centre
TSP	Total Suspended Particle
USA	United State of America

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CHAPTER 01 INTRODUCTION

1.1 Parboiled Paddy

Rice is the main food of most of the population in Sri Lanka. Nearly 34% of total cultivated area in Sri Lanka is occupying with rice production. Approximately 1.8 million farm families are involved in paddy cultivation and they produce about 2.7 million tons of rice annually (Department of Agriculture, 2006).

Parboiled rice, organic rice, brown rice and Individually Quick Frozen (IQF) rice are different varieties of rice products which undergo different manufacturing processes. Nearly quarter of the total production of rice is consumed as parboiled rice in the world. In Sri Lanka, approximately 70% of the paddy production goes through the parboiling process. From around 7,000 of total rice mills in Sri Lanka, about 23% of rice mills practice parboiling process (Department of Agriculture, 2006). The parboiling process is widely used in Eastern, North Central, Uva and North-Western provinces in Sri Lanka.

Parboiling process protects the nutritional qualities of rice including proteins, vitamins, mineral and higher oil content in the bran (TNAU Agritech Portal, 2008). Other than the high nutrient quality, there are numerous advantages of parboiling process. Parboiling process reduces the stickiness of cooked rice and reduces the starch losses during cooking. Resistance of the parboiled rice to insect attack during storage is higher than raw rice. And also parboiling process increases milling yield, recovers poor quality or spoiled paddy, less breakage during milling and improves the quality of byproducts (Blengini, 2009). There are some disadvantages of parboiling process as more energy usage, additional cost, additional time to cook, bran removal is more difficult in milling process and development of more rancidity in parboiled rice than raw rice during storage.

Production of parboiled paddy involves several steps. After harvesting, paddy undergoes operations such as threshing, winnowing, drying, washing, parboiling, milling, packaging and transportation before it goes to the consumer where cooking of rice takes place. All these operations are involved with various environmental impacts.

In most rice mills paddy husk generated by milling operation are used as bio mass fuel to generate steam from husk fired boilers. The emissions from the boiler add many pollutants to environment. In some areas rice husk is dumped in a side of the mill where it can be carried away by wind causing air pollution. The disposal of solid waste is another major environmental problem associated with rice mills. Electricity is used as a major energy source for parboiled paddy production. The generation of electricity also contributes to environmental effects. Parboiling step in the parboiled paddy production consists of three major steps namely soaking, steaming and drying. These operations also consume energy, water and other environmental resources. From this step wastewater, air emissions and solid wastes are added to the environment resulting in adverse environmental impacts.

In order to identify the environmental performance of the parboiled paddy production process, a life cycle environmental impact assessment is required. To facilitate this impact assessment, a life cycle inventory analysis is needed to be carried out. The environmental inputs and output emissions of the parboiled paddy production depend on the selected paddy treatment method and the type of equipment used. Therefore it is necessary to go through each and every step in the life cycle of the production process to identify the total environmental impacts involved. This enables to identify the most environmentally friendly parboiled paddy production method among several alternatives.

In a life cycle impacts assessment the environmental effects caused by the life cycle of a product, service or process are estimated. Environmental impacts can be recognized as climate change, stratospheric ozone depletion, tropospheric ozone creation, eutrophication, acidification, toxicological stress on human health and ecosystems, depletion of resource and many more. These impacts are caused by the environmental emissions of the process and through the consumption of resources, as well as other interventions associated with providing products that occur when extracting resources, producing materials, manufacturing the products, during consumption and at the product's end of life. Life Cycle Assessment (LCA) therefore, can be used to recognize the opportunities for pollution prevention and reductions in resource consumption while considering the entire life cycle of product, service or process.

A complete life cycle environmental assessment of a parboiled paddy production process should target to combine the impacts from 'paddy field to plate'. Such assessments can be used as a decision support tool by three distinct groups namely product producers, consumers and policy-makers. Product producers can use the LCA results to improve the environmental performance of the production system. Moreover, the LCA results can guide product consumers to purchase environmentally friendly products and update policy-makers in making long-term plans and strategies (Cellura, 2012).

1.2 Objectives and Scope of the Project

The overall objective of this project is to assess the environmental impacts of different parboiled paddy production methods adopted in Sri Lanka by using the life cycle assessment approach.

The environmental performance of parboiled rice production with three different parboiling methods will be determined quantitatively and qualitatively and will be compared. The major system boundary that will be considered in the assessment will include the operations from paddy harvesting to rice cooking.

CHAPTER 02 LITERATURE REVIEW

2.1 Parboiling Process

Soaking, steaming and drying are the three major steps involved in paddy parboiling processes which are carried out before the milling process (Blengini, 2009).

2.1.1 Soaking process

The main objective of the soaking process is to increase the moisture level of paddy to about 30% (Miah, 2002). The water requirement for soaking process is nearly 1.3 times of the weight of paddy (Wimberly, 1983; Institute of Post Harvest Technology, 2007). The initial moisture level of paddy needs to be maintained at 14% for precise soaking process. Water absorption rate depends on water temperature and paddy variety. Therefore the water temperature is needed to be maintained at an optimum value to achieve quick and uniform water absorption. Soaking time and temperature affect the solubilization of elements in the rice and also change its color, smell, and taste. Three different soaking methods are practiced in Sri Lanka as described in the “Parboiling of Paddy” published by the Institute of Post Harvest Technology (2007). These methods are shown in table 2.1. Soaking time varies with paddy variety and soaking method. Soaking time requirements for different soaking methods are given in the table 2.1.

Table 2.1: Soaking requirements for different soaking methods

Soaking method	**Paddy variety**	**Soaking time (hours)**
Cold soaking (room temperature)	Short varieties	24
	Medium varieties	36
	Long varieties	48
Hot soaking without maintaining temperature	Short varieties	12
	Medium varieties	18
	Long varieties	18
Hot soaking with maintaining temperature at 70^0C	Short varieties	3.5
	Medium varieties	4
	Long varieties	4

Source: Institute of Post Harvest Technology (2007)

In soaking process, the void spaces in the hull and kernel are filled with moisture absorbed and the air of these void spaces are released. Cold soaking process causes water to penetrate into starch granules and form hydrates through the hydrogen bonding and make swellings. Starch granules exhibit limited capacity for absorbing water and swelling in cold water due to the presence of hydrogen bonds between amylase and amylopsin fraction of starch (Institute of Post Harvest Technology, 2007). During cold soaking, paddy grains release carbon dioxide by respiration (Wimberly, 1983). It causes starch to ferment with off-flavor and lead to excessive development of fungi and other microorganisms in the product (Miah, 2002). Therefore in cold soaking, soaking water needs to be changed in every 12 hours to reduce fermentation and other adverse effects.

During hot water soaking, the granular structures in starch are weakened by the energy supplied by heat and disrupt hydrogen bonds between amylase and amylopsin fraction of starch. This structure gives more surfaces for water absorption in starch granules and increases soaking rate (Institute of Post Harvest Technology, 2007). Temperature of the hot water and paddy mixture should not be more than 75^0C or the paddy will be cooked (Sridhar, 2003). Respiration and fermentation of paddy are controlled in hot soaking method.

2.1.2 Steaming process

Steaming is used to gelatinize the starch in paddy. The starch granules lose their crystalline structure and completely dissolve and fuse together to form a homogeneous structure (Sridhar, 2003). After the steaming operation, the starch granules burst and change their shape and form as one mass which cannot regain their structure after drying. If cracks are present on the surface of kernel, they are heeled up and the endosperm becomes one translucent compact mass. Most of the biological activities are destroyed and enzymes present in the grain are destroyed or temporarily inactivated due to steaming process (Institute of Post Harvest Technology, 2007).

Heating has a significant effect on color and quality of the grain. High steam temperatures more than 100°C and long steaming time cause the grain to significantly become dark in color and hard in texture (Sridhar, 2003). There are two methods of paddy steaming. One method uses pressurized steam and the other non-pressurized steam. The traditional steaming method is mainly used in households for treating paddy with non-pressurized steam. It causes small variations in color, quantity of soluble starch, and the amount of swelling of the rice. In industrial level, saturated steam at the pressure of 1- 5 kg/cm^2 is used for steaming and steaming duration depends on the steaming arrangement (Wimberly, 1983). Small paddy quantities need steaming for two to three minutes and for large quantities around six tons may need steaming for 20 - 30 minutes. In steaming process, the moisture content of paddy increase from 30 to 36% (Wimberly, 1983).

2.1.3 Drying

After steaming process, parboiled paddy needs to be dried until moisture level becomes 14% for safe storage and milling purpose. If paddy is subjected to continuous drying up to 14% moisture level, it causes cracks on the grain and makes the grain to break during milling process (Wimberly, 1983). Therefore drying of parboiled paddy with high moisture levels is recommended to do in three stages. During the first part of drying where moisture level is between 36 - 18%, moisture reduction happens rapidly. In second part of drying (18 - 14% of moisture level), moisture reduction happens slowly. Tempering process is done in between these two drying processes at about 18% of moisture level in paddy (Wimberly, 1983). During tempering, the paddy is removed from the dryer and detained in a chamber for a specified duration (three to six hours) in ambient conditions to equilibrate the moisture and thermal gradients developed in the grains and stresses due to moisture and thermal diffusion processes.

- **Sun Drying of Parboiled Paddy**

Sun drying is the most popular paddy drying method used in domestic and low capacity mills in Sri Lanka. Sun drying method is usually cheaper than mechanical drying. Sun drying depends on solar energy, natural air movement and relative humidity. Therefore drying is extremely depended on good weather conditions. Sun drying is done by spreading paddy on the floor up to one to three centimeters thick layer with the help of planks. These layers need to be continuously turned in order to avoid irregular drying and exposing the grain to unnecessary temperatures which makes cracks in grains. Therefore sun drying is a labor intensive operation. Approximately 0.0929 $m^2$of waterproof floor is required for one kilogram of paddy (Institute of Post Harvest Technology, 2007). After about four hours of drying, paddy is collected for the tempering process which will last for about two to three hours. In tempering, paddy is heaped and covered by mats in the same drying area and kept for about two to three hours in ambient conditions (Patil, 2011). After the tempering process, paddy is again subjected to sun drying.

- **Mechanical Drying of Paddy**

Mechanical dryers such as bag dryers, batch dryers, continuous flow dryers and rotating drum dryers are used specially in high capacity mills (Patil, 2011). Heated air convection type dryers are the most popular dryers. Continuous-flow Louisiana State University (LSU) dryer type is the most common dryer used in Sri Lanka (Institute of Post Harvest Technology, 2007). During mechanical drying, the rate of moisture removal can be regulated and therefore plant operation becomes more uniform.

2.2 Different Parboiling Methods in Sri Lanka

In Sri Lanka, out of total number of rice mills, 77% of rice mills are called custom rice mills and the balance 23% are called commercial rice mills (Department of Agriculture, 2006). Commercial rice mills purchase paddy for processing and sell processed rice. Commercial rice mills engage in large scale parboiling and their average capacity is one ton per hour. Custom rice mills do not employ parboiling process. They only mill raw paddy and home-produced parboiled paddy in small scale (Environmental & Management Lanka (Private) limited, 1999). Some villagers use household methods to produce parboiled paddy and it is only used for their own domestic needs. Following four methods are the major parboiling methods practiced in Sri Lanka (Environmental & Management Lanka (Private) limited, 1999).

1. Traditional cold soaking (Goviya) method
2. Traditional hot soaking (Goviya) method
3. Semi modern method (Cold soaking)
4. Modern method (Indian method)

2.2.1 Traditional cold soaking (Goviya) method

In traditional cold soaking method, water at ambient temperature is used for soaking process in series of rectangular cement tanks. Paddy is subjected to steaming in a separate rectangular metal tank which consists of a perforated metal plate. Paddy is rested on this metal plate and hot water placed under this plate. Steam is generated from this water by direct application of heat from a husk fired furnace below the metal tank. Sun drying is the common practicing drying method in traditional cold soaking parboiling method.

2.2.2 Traditional hot soaking or Goviya method

Traditional hot soaking method is also carried out in a metal tank which has a perforated metal plate inside. In soaking step, the tank is filled with paddy on top of the metal plate and then water is added. Water and paddy mixture is heated using a furnace keeping the temperature at 60-70°C for three to four hours (Environmental & Management Lanka (Private) limited, 1999). The soaking time required depends on paddy variety and temperature. In steaming step, water level is reduced to below the perforated plate in the same tank and heat is applied by a husk-fired furnace located below the tank. Finally paddy is sun dried on a cement floor to reduce the moisture content to proper value for milling and storage.

2.2.3 Semi – modern method

Semi modern cold soaking method is the most common parboiling method used in Sri Lanka. About 98% of parboiled paddy in Sri Lanka is produced by this method due to its low cost and ease of handling. Large cement tanks are used for the soaking process. The amount of water required for soaking paddy is about 1.3 times the weight of paddy (Institute of Post Harvest Technology, 2007). Maximum time that paddy needs to be in water is 48 hours. Prolong soaking times tend to promote development of fungi and other micro-organism in paddy. It is one of the main disadvantages of cold soaking method.

After the soaking process, paddy load is transferred to small cylindrical iron kettles for the steaming process. Steam is produced in husk fired boilers and supplied to kettles. Wimberley (1983) estimated the energy requirement of steaming as 25,000 kCal (99,000 Btu) per one ton of paddy. Institute of Post Harvest Technology (2007) mentioned that 60 kg of 413.69 kPa (60 psi) pressurized steam is required to steam one ton of paddy. Finally paddy is subjected to sun drying.

2.2.4 Modern method

In this method which is also known as Indian method water is used for soaking that is maintained at a temperature 70 ºC in open kettles by recirculating hot water for about four hours. Soaking process is carried out for three to four hours as required depending on the paddy variety (Environmental & Management Lanka (Private) limited, 1999). According to Wimberly (1983), hot soaking process requires 86,000 kCal of energy and about 1.14-1.32 m^3 of water per one ton of paddy. This paddy absorbs about 0.227 m^3 of water. According to studies done by the Institute of Post Harvest Technology (2007), 110 kg of 413.69 kPa (60 psi) pressurized steam is required per one ton of paddy for hot soaking process. The advantages of this method are less soaking period, high quality paddy production and elimination of the fermentation and microorganism in soaked paddy.

According to Wimberley's (1983) estimation the energy requirement for steaming is 25,000 kCal per one ton of paddy. In a publication of Institute of Post Harvest Technology (2007) it is mentioned that 60 kg of 413.69 kPa (60 psi) pressurized steam is required to steam one ton of paddy.

After steaming, paddy is subjected to sun drying or mechanical drying. Sun drying is the most common drying method. Mechanical drying is also used in some mills due to its time efficiency, low labor hours requirement and to avoid undesirable weather conditions. Louisiana State University (LSU) dryer is the most popular mechanical dryer type used in large scale mills in Sri Lanka. It is a continuous-flow dryer and wet paddy enters at the top and flows continuously through the dryer while heated air is blown through the paddy. This is a counter current dryer.

The LSU dryer type has 8-24 tons/day drying capacity. It also requires a heat exchanger and a boiler. High air temperature increases drying cost and damages the milled rice quality. The LSU dryer consists of two sections named as hot partition and cool partition. Hot air goes through the hot partition and paddy is exposed to drying in this section. In cool partition, temperature of hot paddy is reduced and protected from discoloration (Institute of Post Harvest Technology, 2007).

Wet paddy is recirculated in the dryer until moisture level is reached 18% and then subjected to tempering in ambient conditions for three to six hours. After tempering, paddy is again recirculated in the dryer until moisture level reaches 14%. Parboiled paddy requires air temperature up to 100°C during the first drying period and in the second drying period temperature should be kept below 75° C. The first drying period takes about three hours including dryer loading and unloading time. The second drying period takes about two hours (Wimberly, 1983). According to Wimberly (1983) mechanical drying with steam heat exchanger requires 137,000 kCal of energy per one ton of paddy.

2.3 Life Cycle Assessment Methodology

There have been developments to LCA methodologies by several organizations in the world such as the International Organization for Standardization (ISO), Society of Environmental Toxicology and Chemistry (SETAC) and the United Nations Environmental Programme (UNEP).

Life cycle assessment methodology proposed by SETAC (1993) comprises four steps namely goal and scope definition, inventory analysis, impact assessment and improvement evaluation (Furuholt,1995; Rebitzer,2004).

Handbook on Life Cycle Asssessment published by Guinee et al.(2002) presented the operational guide to the ISO standards for LCA. In this guidelines, operational models and data, and scientific background information on LCA methodology are provided. The International Reference Life Cycle Data System (ILCD) Handbook containing general guide for Life Cycle Assessment provides a detailed technical guidance to the ISO 14040 and 14044:2006 standards on Life Cycle Assessment (European Commission, 2010).

Cellura (2012) carried out an LCA study on food products in compliance with ISO 14040 (2006). Blengini (2009) has used the LCA methodology according to ISO 14040 (2006) to evaluate the environmental profile of alternative rice farming and food processing methods in Vercelli, Italy.

LCA methodology developed by the International Organization for Standardization (ISO) is comprised of four major steps (Canals, 2006; Blengini, 2009; Renó, 2011; Roy, 2006).

Four major steps in LCA:

- Goal and scope definition
- Life cycle inventory analysis
- Life cycle impact assessment
- Interpretation of the results

These phases are described in detail by Wenzel (1997) and Guinee (2001) (Canals, 2006). Goal and scope definition consists of identifying the goal, scope, functional unit, system boundaries, description of data categories, criteria for initial inclusion of inputs and outputs, data quality requirements and critical review ((Blengini, 2009; Guinee et al., 2002). Setting of the system boundary in LCA is a very important step due to its large impact on the final results. If selected boundary is too narrow, some important impacts may be undetected. If it is too wide, unnecessary effects may be included and it is an unnecessary burden for the assessment (Blengini, 2009).

Life cycle inventory analysis comprises of a detailed compilation of all the environmental inputs and outputs including air, water and solid emissions at each stage of the life cycle of product (Blengini, 2009). Further, validation of data and relating data to functional unit and process also need to be considered in life cycle inventory analysis (Benedetto, 2009).

ISO standards on LCA introduced selection of impact categories, classification, and characterization as mandatory steps in Life cycle impact assessment (LCIA) (Gagnon, 2002; Blengini, 2009; Kun-Mo Lee, 2004) and normalization and weighting steps as optional steps (Blengini, 2009). Reno (2011) has followed the LCIA guidelines developed by the Center of Environmental Science of Leiden University (Guinée et al., 2002) to evaluate the main environmental impacts of methanol production from sugar cane bagasse.

- **Selection of Impact Categories**

Impact category can be defined as a class representing environmental issues of concern into which life cycle inventory results may be assigned (Guinee, et al., 2002). The selection of impact categories needs to reflect a comprehensive set of environmental aspects related to the product and also needs to depend on the goal and scope of the study (Renó, 2011). Guinée et al. (2002) separated impact categories in to three groups named as 'baseline' impact categories, 'study-specific' impact categories and 'other' impact categories. This grouping has been done according to the environmental relevance in relation to LCA and the availability of adequate characterization methods. The environmental impacts identified for each group by Guinee et al (2002) are shown in table 2.2. Appropriate impact categories related to goal and scope defined for the LCA need to be identified and selected from above mentioned groups.

According to the guidelines developed by Guinée et al.(2002), all or part of the "baseline impact categories" need to be included in any LCA study. Depending on the goal and scope of the LCA and if appropriate data are available, impacts from "study-specific impact categories" can be selected. The "baseline impact categories" are included in almost all LCA studies (Renó, 2011).

Table 2.2: Groups of impact categories

Baseline impact categories	Study-specific impact categories	Other impact categories
Depletion of abiotic resources	Impacts of land use	Depletion of biotic resources
Impacts of land use	loss of life support function	
land competition	loss of biodiversity	Desiccation
Climate change	Ecotoxicity	Odour
Stratospheric ozone depletion	freshwater sediment ecotoxicity	malodourous water
Human toxicity	marine sediment ecotoxicity	
Ecotoxicity	Impacts of ionizing radiation	
Freshwater aquatic ecotoxicity	Odour	
marine aquatic ecotoxicity	malodourous air	
terrestrial ecotoxicity	Noise	
Photo-oxidant formation	Waste heat	
Acidification	Casualties	
Eutrophication		

Source: Guinee et al (2002)

➢ Characterization of environmental impacts

When the impact categories are selected the emission inventories are classified into these impact categories. These classified emissions are quantified in characterization step in terms of a common unit. For the characterization of impacts, characterization factors are used. In different LCA applications characterization factors from different sources of reference in literature have been used for the selected impact categories. Canals (2006) carried out an evaluation of the environmental impacts associated with apple production systems in New Zealand using impact categories which are usually considered in LCA: climate change, photochemical oxidants formation, acidification, nitrification, human toxicity (air, water and soil) and ecological toxicity (acute and chronic for aquatic ecosystems, and chronic for terrestrial ecosystems). In his work characterization factors from Hauschild (1998) have been used to carry out the characterization of environmental impacts associated with apple production systems. Hokazono (2012), who carried out a comparison among environmental impacts of rice production by three farming systems in Japan used only four impact categories including global warming, acidification, eutrophication and non-renewable energy.

Characterization factors used for the impact assessment of Hokazono (2012) were taken from several references. Characterization factors for global warming were taken from IPCC (2007) and for impact categories acidification and eutrophication from Heijungs et al (1992). Characterization factors related to non-renewable energy were taken from Jungbluth (2009) (Hokazono, 2012). Blengini (2009) used characterization factors from IPCC (2001) to determine the impact of green house gas effect and characterization factors from Swedish Environmental Management Council (SEMC) (2000) to determine the values of other impact categories in LCA of rice in Vercelli, Italy. Cellura (2012) has refered to Environmental Product Declaration (EPD) given in the International EPD Cooperation (2008) for the selection of impact categories and related characterisation factors. Eco-Indicator 99 method is also used in life cycle asseement of biodiesel, diesel and gasoline (Evanthia, 2012).

- **Normalization**

According to the definition of ISO 14042, the normalization is "calculation of the magnitude of indicator results relative to reference information" (Guinée, et al., 2002). The goal of the normalization is to establish a common reference to enable comparison of different environmental impacts and it helps to show to what extent an impact category has a significant contribution to the overall environmental problem (Renó, 2011). Normalization facilitates the interpretation of the results (Renó, 2011). Reference information which is named as a "Normal" value can be determined related to a given community (e.g. county or the world), person or other system for a given period of time. Selection of the "Normal" value depends on the goal of the study (Guinée, et al., 2002). There are many normalization methods that have been developed and these methods are specified for a limited region or for a limited number of impact categories (Sleeswijka, 2008). Huijbregts et al. (2003) developed normalization factors for the world, Western Europe and the Netherland for the reference year 1995 (Sleeswijka, 2008). Wenzel et al (1997) developed normalization factors for Denmark in 1990.

In an environmental assessment carried out by Canals (2006) for apple production in New Zealand using LCA, normalization factors given by Hauschild (1998) have been used. Although there were no normalization values related to New Zealand context available in Hauschild's work (1998), Canals (2006) has used normalization factors related to a world inhabitant for climate change and Danish inhabitant for all other impacts in 1990. Reno (2011) used European normalization references in his study on a life cycle assessment of the methanol production from sugarcane bagasse. European normalization references represent the total emissions of Western European countries of the year 1995 (Renó, 2011).The final step of the LCA methodology involves the interpretation of life cycle inventory analysis and life cycle impact assessment stages, in order to find significant environmental issues and compare alternative scenarios (Blengini, 2009).

2.4 Life Cycle Assessment Software

Nowadays several LCA software are used in many LCA studies. LCA software include mechanisms to model the life cycle of the products, databases with generic data on processes and flows, databases with LCIA models and their characterization factors, calculation features for the different stages of the LCIA such as characterization, normalization and weighting. Further, LCA software are facilitated to do documentation, reporting and sensitivity analysis. SimaPro, GaBi and Umberto are the most popular software used in LCA studies. Blengini (2009) applied the SimaPro 7 (2006) software in his LCA study on the life cycle of rice (from the paddy field agricultural processes, drying storing, refining, packaging and delivering to the supermarket) to implement the LCA model and carry out the assessment. Reno (2011) has used the SimaPro software version 7.01 to compute the main environmetal impacts of methanol production based on the inventory data in the software. Evanthia (2012) carried out a life cycle assessment of gasoline and diesel using the SimaPro 5.0 Pre: Simapro databases.

CHAPTER 03 PARBOILED PADDY PRODUCTION PROCESS INVENTORY

The major steps in harvesting and converting paddy to cooked parboiled rice are,

- Harvesting
- Threshing
- Winnowing
- Drying
- Washing
- Parboiling
- Milling
- Packaging
- Cooking

Other major steps involved in parboiled paddy production when considering the life cycle are,

- Transportation
- Steam generation
- Electricity generation

The inventory determination for the life cycle assessment of parboiled rice production and information on all other steps involved in the rice production process including major steps when the life cycle is considered are described in sections 3.1 to 3.9.

Although all rice producers have to go through these steps, there are many differences in size, capacity, design and arrangement of the equipment in rice mills due to various factors such as capacity of the mill, operational requirements as loading, safety features, capital investment and auxiliary equipment (fans, cyclone separators, elevators and etc.). Further the processing methods and equipment selection in paddy fields also vary due to many reasons such as the size of the paddy field, economy and technical knowledge of the farmers.

3.1 Emission Inventory of Electricity Generation

Electricity is used as an energy source in the parboiled rice production. All the electric equipment in milling operations and water pumps which use for soaking process and cleaning process are operated from electricity. Therefore it is necessary to consider the impacts due to the emissions of electricity power usage when carrying out the life cycle environmental assessment for parboiled rice production. The inventory of emissions per one MWh electricity generation using diesel engine is shown in Appendix 1.1.

In 1995, the hydroelectric schemes have contributed over 95% of Sri Lankan electricity generation. This scenario has changed during the last decade due to electricity demand growth and limited hydropower resources. Thereafter thermal power generation contributes around 40-50% of the national electricity requirement. Mostly the furnace oil and diesel oil are used for thermal power generation in Sri Lanka. Emissions from these thermal power electricity generations significantly contribute to air pollution in the country. From the Sri Lankan total electricity generation in 2010, 46.9% was from oil fired thermal power plants, 46.2% was from major hydropower and the balance 6.7% was from the new renewable energy (Sri Lanka Sustainable Energy Authority, 2010).

According to the study done by Sri Lanka Sustainable Energy Authority (2010), heavy sulpher fuel oil, residual oil, diesel, low sulpher fuel oil and naptha are used as fuel in different types of thermal power plants in Sri Lanka. Table 3.1 indicates the GHG and other emissions of electricity generation from furnace oil and diesel oil (Ministry of Environment, 2011). Diesel oil burning emissions mentioned in the table 3.1 are used in the emission inventory calculations from electricity usage in parboiled paddy production in this work and are shown in Appendix 1.1.

According to the “Sri Lanka Energy Balance (2010)” published by Sri Lanka Sustainable Energy Authority (2010), 18.3 GWh electricity production from diesel engine in 2008 has required 6.2 million liters of diesel oil.

Table 3.1: GHG and other emissions from electricity generation

Fuel		**Emissions (Gg)**						
Type	**Amount (kt)**	**CO_2**	**CH_4**	**N_2O**	**CO**	**NO_X**	**NMVOC**	**SO_2**
Heavy fuel oil	498.80	1535.58	0.06	0.01	0.30	4.01	0.10	29.93
Diesel	481.59	1530.25	0.06	0.01	0.31	4.17	0.10	2.89
Total		3065.84	0.12	0.02	0.61	8.81	0.20	32.82

Source: Ministry of Environment (2011)

3.2 Boiler Emissions in Steam Generation

Rice husk based furnace boiler systems are generally used to meet thermal energy demand of paddy parboiling process in Sri Lanka. Steams generated by husk fired boilers are used for hot soaking, steaming and mechanical drying operations in parboiling process. The emissions from paddy husk combustion depend on the quantities and qualities of husk consumed and on the design of the combustion systems. According to the study carried out by Chungsangunsit (2009) on "Emission Assessment of Rice Husk Combustion for Power Production", the emissions of rice husk burning is as shown in table 3.2.

Table 3.2: Emissions of rice husk burning

Parameter	**Emissions (kg/hr) (Rice husk burning rate = 10.63 t/hr)**
CO_2	16,013.56
CO	81.52
NO_2	12.47
SO_2	3.72
TSP	1.03
Fly ash	1,560.00
Bottom ash	323.00

Source: Chungsangunsit (2009)

Solid wastes are produced by bottom ash and fly ash. According to the Rice Knowledge Management Portal of Hyderabad (2011) about 75% of husk contains organic volatile matters and other 25% of the weight is converted in to ash during burning. This rice husk ash contains around 85-90% amorphous silica and it is a carbon neutral green product and a good super-pozzolan which can be used to make special concrete mixes. Chemical composition of rice husk ash at 600 ^{0}C is given in table 3.3 as mentioned in Weiting Xu (2012).

Table 3.3: Chemical composition of rice husk ash

Chemical Properties	**Percentage of Composition (%)**
Loss on ignition	3.13
Silicon Dioxide (SiO_2)	91.71
Calcium Oxide (CaO)	0.86
Aluminum Oxide (Al_2O_3)	0.36
Ferric Oxide (Fe_2O_3)	0.9
Magnesium Oxide (MgO)	0.31
Potassium Oxide (K_2O)	1.67
Sodium Oxide (Na_2O)	0.12

Source: Weiting Xu (2012)

The emission inventory determination of steam generation is shown in Appendix 1.2. The emissions of rice husk burning mentioned in the table 3.2 are used in the emission inventory calculations from husk fired boiler usage in parboiled paddy production. The average heat value of husk is 3,000 kCal/kg (Wimberly, 1983). Paddy with 20% of husk gives 200 kg of husk per one ton of paddy. Assuming 50% efficiency of husk fired boiler, heat available from the 200 kg of husk will be 300,000 kCal (Wimberly, 1983).

3.3 Harvesting, threshing and winnowing

Harvesting, threshing and winnowing are the final field practices in paddy production. In Sri Lanka, 30% of total farm power requirement of paddy production are consumed by harvesting and threshing operation (Mahrouf, 2003). Depending on the variety and condition of the crop, 3,000 to 4,000 labor days per square kilometers of paddy fields are required for harvesting, threshing and winnowing (Mahrouf, 2003).

Four wheel tractors or low capacity mechanical threshers are used for threshing. Combine harvesters which can introduce as a machine that combines three separate operations comprising harvesting, threshing and winnowing into a single process are only used in few areas. Average labor hour requirements for harvesting, threshing and winnowing per one square kilometer of paddy field are shown in table 3.4 (Mahrouf, 2003).

Table 3.4: Average labor hour requirements for harvesting, threshing and winnowing

Operations	**Average total labor hour requirement (hrs/km^2)**		
	Manual harvesting and threshing with four wheel tractor	**Manual harvesting and threshing with low capacity thresher**	**Combine harvester**
Cutting with sickle, bagging, gathering and heaping	14,000	14,000	3,200
Threshing with four wheel tractor	6,000	-	
Threshing with low capacity thresher	-	3,000	
Winnowing and bagging	4,000	4,000	
Total	24,000	21,000	3,200

Source: Mahrouf (2003)

Comparison between average cost and total output of different techniques are as shown in following table 3.5 (Mahrouf, 2003).

Table3.5: Comparison of harvesting, threshing and winnowing

Parameter	**Manual harvesting and threshing with four wheel tractor**	**Manual harvesting and threshing with low capacity thresher**	**Combine harvester**
Average cost of harvesting, threshing and winnowing	Rs. 1,630,000 / km^2	Rs. 1,589,000 / km^2	Rs. 637,500 / km^2
Average output of harvesting, threshing and winnowing	472,000 kg/ km^2	477,000 kg/ km^2	502,000 kg/ km^2

Source: Mahrouf (2003)

Average labor requirement can be reduced by combine harvester and therefore it provides solutions to overcome the scarcity of labor during peak harvesting season. Combined harvester reduces harvesting time, post-harvest losses and increases the quantity of average paddy production with higher quality than other methods. Although combined harvester has many advantages, it has limited usage because of its high investment cost, technical problems and requirement of skilled machine operators. Most of Sri Lankan farmers own small plots and thus its non-profitable to invest on large machineries.

- **Harvesting**

Most of the paddy fields in Sri Lanka are harvested manually using sickles. Around 1-2% of the paddy production is lost during harvesting (Institute of Post Harvest Technology, 2007). The details of material balance calculation values of harvesting and emission inventory estimation are shown in Appendix 1.3.

- **Threshing**

There are power operated semi axial, axial flow, rasp bar and wire loop type threshers used in Sri Lanka. These threshers are operated using 3.73 to 7.46 kW (5 - 10 hp) electric motors or diesel engines or tractors and its work capacity varies from 200-1300 kg per hour. According to Palipane (2003), the use of the axial flow mechanical thresher has become increasingly popular in Sri Lanka. However, according to the publication of Institute of Post- Harvest Technology (2007), at present a higher percentage of the Sri Lankan farmers use four wheel tractors for threshing process. Further, Institute of Post- Harvest Technology (2007) has introduced a low capacity thresher as a very suitable method for threshing due to its many advantages and these threshers are becoming popular among Sri Lankan farmers as well. Around 1-2% of the paddy production is lost during threshing process (Institute of Post- Harvest Technology, 2007). Palipane (2003) mentioned the threshing rates, threshing efficiencies, qualities of threshed paddy and the labor requirements for different threshing methods in Sri Lanka are given in the tables 3.6, table 3.7 and table 3.8.

Table 3.6: Threshing rates and efficiencies

Threshing Method	**Threshing Rate (kg/hr.)**	**Threshing Efficiency (%)**
Buffalo	120	96.0
Tractor	2000	97.4
Mechanical thresher	400	99.9

Source: Palipane (2003)

Table 3.7: Qualities of threshed paddy by different methods

	Tractor (%)	**Mechanical Thresher (%)**
Impurities	7.8	0.3
Cracked grains	11.7	6.3
Loss in head rice	7.0	2.7

Source: Palipane (2003)

Table 3.8: Labor requirements for threshing*

	Buffalo	**Tractor**	**Mechanical Thresher**
Transporting	37.7	37.9	11.5
Threshing	43.9	16.6	10.1
Cleaning	3.5	3.6	0.9
Total	85.1	58.1	22.5

* Number of man hours per one ton of threshed paddy production

Source: Palipane (2003)

Palipane (2003) considered the threshing rate of mechanical thresher as 400 kg/hr, with 99.9% efficiency. Baruah (2004) has stated that the 3.7 kW (~5hp) power operated thresher has a capacity of 400 kg/hr. According to the details of Palipane (2003), the average rice yield of paddy field is 350,000 kg/ km^2. Mahrouf (2003) has obtained 30 labour hours per hectare for mechanical threshing.

Rice straw is a main solid waste in rice production process which is obtained in threshing process. According to the Wijesundara (1995), grain to straw weight ratio is one to one. The details of material balance calculation values and emission inventories of threshing operation are shown in Appendix 1.4.

➢ **Winnowing**

Winnowing process is carried out to remove impurities such as weed seeds, half filled grains, dust, chaff and straw. Therfore the winnowing process is an important step to obtain clean paddy for storage and further processes. In Sri Lanka winnowing process is done by fans attached to tractors or by manually. Mahrouf (2003) stated that winnowing and bagging process required 4,000 labour hours per one square kilometers of paddy field. And the resulted paddy weight after manual harvesting and threshing with low capacity thresher was 477,000 kg/km^2 (Mahrouf, 2003). According to the Tamilnadu Agricultural University in Coimbatore, 0.7457 kW (1hp) motor can winnow 500-750 kg of moisturized paddy in one hour (Patil, 2011). The details of material balance calculation for winnowing are shown in Appendix 1.5.

➢ **Emissions of use of Diesel in Threshing and Winnowing**

The emissions from threshing and winnowing are mainly from the diesel fuel combustion from tractors and threshers. According to the Ministry of Environment (2011), Sri Lankan agricultural processes depend on both traditional and modern technologies for operations such as land clearing, land preparation and harvesting. Therefore some people use tractors, water pumps and harvesters and others depend on cattle or manual labor. It also indicates that diesel is used for tractors and kerosene for operating water pumps. The emissions of diesel fuel combustion from road transport which are mentioned in table 3.9 can be considered as same as emissions from diesel combustion in tractors (Ministry of Environment, 2011).

Table 3.10 shows the emissions of diesel fuel combustion in a farming tractor according to the study of Sheehan (1998). The values in table 3.9 are used in estimating the emissions of low capacity thresher motor and winnowing fan motor which are operated by the tractor engine in this work. Sheehan (1998) has also mentioned emissions of diesel fuel combustion in farming tractor in his work as shown in Table 3.10.

Table 3.9: Emissions of road transport sub-sector in 2000

	Air Emissions						
	CO_2	CH_4	N_2O	CO	NO_X	NMVOC	SO_2
Emissions (g) per 1kg diesel fuel burn	3,177.50	0.21	0.02	43.33	34.67	8.66	6.00
Emissions (g) per 1MJ diesel fuel burn	73.05	0.0048	0.0005	1	0.8	0.2	0.14

Source: Ministry of Environment (2011)

Table 3.10: Emissions of diesel fuel combustion in farming tractor

Emissions	**Qty (g/MJ diesel fuel burned)**
Hydrocarbons	0.085
CO	0.32
NO_X	0.89
PM_{10}	0.041
SO_2	0.12
CH_4	0.0042
N_2O	0.0019
CO_2	75.5

Source: Sheehan (1998)

When comparing above mentioned emissions of diesel fuel burning related to tractor which are given by Sheehan (1998) (see table 3.10) and Ministry of Environment (2011) (see table 3.9), the quantitative similarities can be identified in emissions of CO_2, SO_2, NO_X, N_2O and CH_4. The estimation of emission inventories of threshing and winnowing are shown in Appendix 1.4 and 1.5 respectively.

3.4 Drying of threshed paddy

Most of the farmers in Sri Lanka depend on sun drying of threshed paddy. Sun drying reduces about 20% of threshed paddy moisture content that is about 14%. Sri Lanka is located close to the equator and therefore a marked seasonal variation is not experienced in solar radiation other than in mountainous regions. National Renewable Energy Laboratory (NREL) of USA has developed a solar resource map of Sri Lanka (Sri Lanka Sustainable Energy Authority, 2010). According to this solar resource map, over most of the parts in flat dry zone, which accounts for about two thirds of the land area receives solar radiation varying from 4.0 – 4.5 kWh/m^2/day (Sri Lanka Sustainable Energy Authority, 2010).

Normally sun-drying takes one or two days depending on the weather condition. Losses during sun drying may be due to rodents and birds and undesirable weather conditions. Around 0.05% of the paddy production is lost during drying and cleaning processes (Institute of Post- Harvest Technology, 2007). The details of material balance calculation and the values of sun drying are shown in Appendix 1.6.

3.5 Washing

Washing process is done in the same tank which is also used for the soaking process. In Sri Lanka fresh water used in parboiling mills is collected from nearby ponds, lakes or rivers. Water is filled by electric water pumps and finally used water is drained off by gravity through the holes with perforated plates located in tanks. The chaff and other light weight matters which float on water are removed manually. Dissolved dust and other solid particles are removed with draining water through the discharge valve. Water quantity required for washing purpose is taken as same as the amount of water required for soaking process which is about 1.3 times the weight of paddy (Institute of Post Harvest Technology, 2007). Generally eight tons per day capacity mills require 0.465 m height, 0.743 m long and 0.743 m width tanks for soaking and cleaning processes.

The effluent discharged from the paddy washing process containes only sand, muds and solid particles. No dissolved organic substances are observed in this wastewater (Environmental & Management Lanka (Private) limited, 1999). The details of material balance calculation of washing operation are shown in Appendix 1.7.

3.6 Parboiling Process

The process description of the soaking, steaming and drying of the parboiling process have already been discussed in Chapter 2. According to the Institute of Post Harvest Technology (2007) around 1-2% of the paddy production is lost during parboiling process. Paddy parboiling involves paddy soaking, steaming and drying operations.

3.6.1 Paddy soaking

In the cold soaking step paddy after harvesting, threshing, winnowing, drying and washing is soaked using water at ambient temperature. Water is feed by 1.119 kW (1.5 hp) pump. Average cold soaking time is 48 hours and soaking water is changed every 24 hours. The input materials include paddy, water and diesel used in water pumping. The outputs include soaked paddy, soaked wastewater and diesel fuel burning emissions due to the electricity used in water pumping. The inventory calculated is summarized in Appendix 1.8.

In the hot soaking step paddy is soaked using water at 70^0C temperature and average hot soaking time is 4 hours. Water is feed by 1.119 kW (1.5 hp) pump. The input materials include paddy, water, diesel used in water pumping and paddy husk used in steam generation. The outputs include soaked paddy, soaked wastewater, emissions due to the electricity used in water pumping and husk fired boiler emissions. The inventory calculated is summarized in Appendix 1.9.

The wastewater generated from parboiling mills mainly contains wastewater discharged from soaking process and these effluents do not contain any toxic compounds or pathogenic bacteria. However, nitrogen and phosphorous are present in this paddy soak wastewater. According to Environmental & Management Lanka (Private) limited (1999) most of Sri Lankan mills discharge effluent to environment without any treatment. And therefore this may lead to sever adverse environmental effects.

Karunaratne (2010) experimentally determined the wastewater characteristics of hot soaking wastewater samples and cold soaking wastewater samples of two paddy varieties namely “LD 356 Red Rice” and “BG 300 White Rice”. Characteristics of COD, BOD, Total Kjeldhal Nitrogen and Total Phosphorous values of these wastewater samples are used in the emission inventory determination of the soaking operation as shown in appendix 1.8. According to the Institute of Post Harvest Technology (2007) recommendations, the soaking water should be changed with fresh water in every 12 hours. But most of the mill owners change soaking water only in every 24 hours (Kaunaratne, 2010). Karunaratne (2010) has determined the characteristics of wastewater by changing water once a day.

According to Queiroz (2007), compositional variations of parboiled rice effluents occur due to the variation in rice parboiling method. Queiroz (2007) mentioned that the temperature and length of soaking process allowed different quantities of protein and soluble carbohydrates to lose into wastewater. Table 3.11 shows the characteristics (COD, N-KTN, P-PO_4^{-3}) of parboiled rice effluents taken from maceration tanks in Brazil (Queiroz, 2007).

Table 3.11: Characterization of the parboiled paddy wastewater

COD (mg/l)	**N-KTN (mg/l)**	**P-PO_4^{-3} (mg/l)**
4090	75.60	22.01
6480	69.85	57.95
5022	72.10	75.92
4514	88.03	32.28
2821	48.43	52.82
3128	95.04	93.90
2578	80.14	84.91
5022	25.40	11.75

Source: Queiroz (2007)

Calculated average values of compositional variations given in table 3.11 are 4206.8 mg/l of COD, 69.32 mg/l of N-KTN and 53.94 mg/l of P-PO_4^{-3} (Queiroz, 2007).

3.6.2 Steaming

For steaming 25,000 kCal of energy is required for one ton of paddy. The input materials of the steaming step include soaked paddy and paddy husk used in steam generation. The outputs include steamed paddy and husk fired boiler emissions. The inventory calculated is summarized in Appendix 1.10.

3.6.3 Drying of soaked and steamed parboiled paddy

- **Mechanical drying**

In the mechanical drying step, paddy is dried by LSU mechanical dryer with steam exchanger. For this 137,000 kCal of energy is required for one ton of steamed paddy. The input materials include steamed paddy and paddy husk used in steam generation. The outputs include paddy with 14% moisture, husk fired boiler emissions and paddy losses. Total paddy losses in parboiling process that is 2% is considered to occur in the drying operation. The inventory calculated is summarized in Appendix 1.11.

- **Sun drying**

In the sun drying step, paddy is dried by using solar energy. Therefore the input materials only include steamed paddy and outputs include paddy with 14% moisture and paddy losses. The inventory calculated is summarized in Appendix 1.12.

3.7 Milling

Custom mills and commercial mills are the two different types of rice mills found in Sri Lanka. From the total milling capacity of the country, 60% is done in custom mills and the rest of 40% is done in commercial mills (Palipane, 2003). All the custom rice mills can be categorized into two types namely, traditional and semi modern type. Commercial rice mills consist of 25% traditional type, 35% semi modern type and 40% modern type rice mills (Palipane, 2003). In traditional mills, dehusking and polishing operations are done by one or more steel hullers. Semi modern mills use rubber roll sheller for dehusking and one or more steel hullers are used for polishing purpose. But modern rice mills use distinct machines for each milling operation such as precleaner, destoner, rubber roll sheller, paddy separator, rice polisher and grader. Traditional and semi modern rice mill's products have low quality with discolorations, impurities and high percentage of grain breakage. According to Palipane (2003), traditional and semi modern rice mills have low rice recovery about 60-65% and modern rice mills have 68-70% of recovery. Modern type rice mill is the most common commercial mill type in Sri Lanka. Modern type commercial rice mills in Sri Lanka generally consist of following sections.

- Rubber roll huller to remove the paddy husk from the paddy grain
- Air aspirator to separate husks and grains

- Tray type paddy separator to paddy separation from rice
- Vertical abrasive whitener to remove bran
- De-stoner to clean the paddy
- Grading equipment with air aspirator and vibrating sieve
- Bucket elevators used as conveying equipment

The machinery requirements in modern type mills to produce one ton of rice per hour as mentioned in Palipane (2003) is shown in table 3.12.

Table 3.12: Machinery requirements in modern type mills

Machinery	**Function**	**Power requirement (kW)**
Pre-cleaner	Paddy cleaning	1.68
Rubber roll sheller	Dehusking	4.10
Separator	Removing paddy grains from rice	1.68
Abrasive polisher	Polishing rice	5.59
Jet pearler	Polishing rice	11.18
Destoner	Removing sand and stones from rice	1.68
Five elevators	Conveying of grain	5.59

Source: Palipane (2003)

Although the main target of rice production is refined rice, the by-products such as broken grains, rice flour, husks, straws and brans are also produced. Quantities of husk, bran and broken grains vary with the variety of paddy. The long grains produce husk about 22–24%of the paddy mass (Harry, 1985). The production of rice bran depends upon the degree of milling process and amount of whitening. Generally, it accounts for 5–8% of the paddy mass (Juliano, 1985). Roy (2006) in his study of energy consumption and cost analysis of parboiling processes in Bangladesh has assumed that the husk and bran produced is about 22% and 7% of the paddy mass respectively. According to Patil (2011), during milling process about 78% of weight is received as rice, broken rice and bran and 22% of weight as husk. About 2% of the rice production is lost during milling processes (Institute of Post- Harvest Technology, 2007). In this work, for the determination of inventory involved in milling, modern type mill is considered where cleaning, milling and separation are operated by electricity. The inputs to this operation involve parboiled paddy and diesel for electric machines. Outputs include milled rice, paddy husk, bran and losses. The emission due to generation of electricity is calculated as described in section 3.1. The inventories determined are summarized in Appendix 1.13.

3.8 Rice cooking

Biomass, kerosene, electricity, LPG are found as the main energy resources used for cooking purpose in Sri Lanka and among those energy sources biomass is the most popular one. According to the Energy Balance (2010) carried out by the Sri Lanka Sustainable Energy Authority for the year 2010, the total primary energy requirement of the country is met with biomass (45.8%), hydropower (11.1%) and imported petroleum (40.9%). Biomass is the most common source of energy supply in the country and the largest use of biomass is for cooking purposes in the domestic sector. Energy Balance (2010) mentioned that LPG also has succeeded in getting penetrated in to the domestic sector as a fuel source for cooking by displacing a portion of the biomass usage.

Household sector consumes approximately 80% of the energy from biomass, 10% from petroleum and 9% from electricity (Wickramasinghe, 2011). Fuel wood and crop forest residues are the common bio mass used by most of the Sri Lankan rural households. According to Wickramasinghe (2011), 18 million people from the entire population of 20 million in Sri Lanka are carrying out their day to day cooking requirements by using wood, locally obtainable materials and traditional combustion technologies. The biomass mix used by Sri Lankan households contains 92% solid wood and 8% residue which consists of coconut fronds and shells, pods, and stalks (Wickramasinghe, 2011). Sri Lankan households use biomass due to its high availability, lower cost and high calorific value of fuel wood. Wickramasinghe (2011) found out through a field survey in 2006/2007 that most of the house-holds were using semi-circular mud stoves for cooking purpose. Efficiency of this type of semi enclosed stove is about 13% (Perera, 2002). Firing wood in households generates various emissions. Emission factors are defined to express the emissions in grams per one kilogram of air dried fuel wood. Selected emission factors for fuel wood fired semicircular mud stoves presented in Perera (2002) are as shown in table 3.13.

Table 3.13: Emission factors for fuel wood fired semi-circular mud stove

Emissions	**Emission Factors (g/kg of air dried fuel wood)**
CO_2	1104.01
CO	74.84
CH_4	8.69
TSP	8.80
SO_x	0.44
NO_x	1.25

Source: Perera (2002)

The cooking duration of parboiled milled rice is longer than that of non-parboiled milled rice. This variation can be explained by indicating the interaction of components such as proteins, lipids and starch during parboiling (Kato, 1983). Rao (1966) also described about greater amount of bran pigments in milled parboiled rice than in milled non-parboiled rice which had under gone equal degree of milling. They hypothesized that the inner bran layers are infused into the endosperm during parboiling and therefore these greater amounts of hydrophobic proteins and lipids from the bran can cause to reduce the water absorption rates and increase cooking durations (Billiris, 2012). Gunasekara (2011) has also discussed on the higher energy consumption of parboiled rice than that of non-parboiled rice in his work of “Effect of grain shape and pre-soaking on cooking time and cooking energy”.

The amount of water and thermal energy are the two important variables in rice cooking process. The calorific value is an important factor in determining the thermal energy. The net calorific value of wood which are stacked-air dried to 20% of moisture level is 14760 kJ/kg (Bio Mass Energy Center, 2008). Perera (2002) used the heating value of fuel wood as 15,000 kJ/kg in their analysis of “Fuel wood fired cook stoves in Sri Lanka and related issues”.

Rice needs to be washed and cleaned before being cooked. In the cooking process when the rice is cooked until the white core is not observed, the rice sample is considered as completely cooked. Desikachar (1961) reported that the moisture content of cooked rice samples is in the range of 72–73% of raw rice. Billiris (2012) also experimentaly found out that the moisture content of cooked parboiled milled rice was equal to the 72% when water to rice ratio of 2.75 was used. Parboiled milled rice required least energy to be cooked with 2.75 of water to rice amount was 964 kWh per one ton of uncooked rice (Billiris, 2012). Using the above discussed data the inventory involved in rice cooking step is determined and the summary of this is shown in Appendix 1.14.

3.9 Transportation

Paddy and rice transportation is also a major operation in parboiled rice production industry. Transportation of paddy and milled rice can be divided into the following three major stages when considering paddy harvest step to cooked rice step.

- Paddy transport from field to mill
- Milled rice transport from mill to market
- Milled rice transport from market to consumers

Road transport is the most popular mode of transport used in the movement of paddy and rice from the producing fields to the ultimate consumer in Sri Lanka. Trucks and tractors are the vehicles used for transportation. Trucks and tractors are used to transport paddy from fields to the mills and trucks are used to transport milled rice from mills to markets. There is no precise information regarding the distances of paddy and rice transportation in Sri Lanka. Therefore estimation of emission inventories related to paddy transportation is not able to perform reasonably accurately as data on average transportation distances in Sri Lanka are lacking. Therefore as one case of transportation, environmental emissions of transportation from Anuradhapura to Colombo (206 km) by medium truck are calculated in the inventory analysis.

- **Emissions of transportation**

Sri Lankan transportation mainly depends on gasoline and diesel fuels. According to the report of "Sri Lanka's Second National Communication on Climate Change" which was publish by Ministry of Environment in 2011, the amounts of fuel used and emissions of GHG and other gasses from road transport sub-sector for the year 2000 is as shown in table 3.14.

Table 3.14: Emissions of road transport sub-sector in 2000

Diesel Fuel	**Emissions (Gg)**						
Amount (kt)	**CO_2**	**CH_4**	**N_2O**	**CO**	**NO_X**	**NMVOC**	**SO_2**
1175 .15	3734.04	0.25	0.03	50.92	40.74	10.18	7.05

Source: Ministry of Environment (2011)

Sri Lanka Sustainable Energy Authority (2010) in their publication on "Sri Lanka Energy Balance 2010" has indicated that the net calorific value of diesel oil is 10.50 kCal/ kg and Ceylon Petroleum Corporation (2011) data indicate the density of diesel is 0.82 kg/l. The table 3.15 shows non CO_2 emissions of individual diesel vehicles (Ministry of Environment, 2011). As seen in table 3.15, road transportation consists of different vehicles which are having individual emissions. Depending on the extent of the fuel consumption by each vehicle category, an average emission value for the road transport sector for each emission type and for each year was evaluated by the Ministry of Environment (2011).

In a life cycle assessment of paddy parboiling process important impacts need to be considered are the environmental interventions of emissions from the transportation using diesel as well as other diesel consuming units. In this the environmental interventions involved in the production process of diesel are also important. There are different types of studies done on life cycle assessment of diesel production (Sheehan (1998); Furuholt (1995); Evanthia (2012)).Their results are highly depended on the product specifications, production processes, assumptions that are made, the type of oil refineries and their technology and the properties of the raw oil. Fuel consumption and combustion emissions depend on vehicle type, engine technology and driving conditions.

Table 3.15: Non CO_2 emissions of individual road vehicle types (Diesel)

Vehicle type	Emissions (t/TJ)				
	CO	CH_4	NO_X	N_2O	NMVOC
Car	0.3	0.002	0.3	0.004	0.07
Medium bus	0.4	0.001	0.4	0.004	0.1
Jeep	0.4	0.001	0.4	0.004	0.1
Heavy bus	0.9	0.006	1	0.003	0.2
Truck	0.9	0.006	1	0.003	0.2

Source: Ministry of Environment (2011)

Medium and heavy-duty diesel engines are usually assessed depending on the actual work supplied by the engine. Sheehan (1998) compared the life cycle flows of biodiesel and petroleum diesel to assess the work delivered by heavy duty diesel engines. Diesel fuel requirement depends on the fuel economy of the engine. Fuel economy differs from one engine to another engine. Sheehan (1998) has considered a lower heating value of diesel fuel, 43.5 MJ/kg in his LCA study. In literature fossil diesel energy content is recorded as 35.7 MJ/liter (Evanthia, 2012). The average yield of different trucks presented in work done by De Souza (2013) is shown in table 3.16.

Table 3.16: Average yield of different types of diesel vehicles

Category of vehicle	Fuel	Average yield (km/l)
Light trucks	Diesel	3.9
Medium trucks	Diesel	3.0
Heavy trucks	Diesel	2.6
Urban buses	Diesel	2.3

Source: De Souza (2013)

In Sheehan's work (1998) on LCA the following major operations have been included within the boundary of the petroleum diesel life cycle.

- Extraction of crude oil from the ground
- Transport of crude oil to an oil refinery

- Refining of crude oil to diesel fuel
- Transport of diesel fuel to its point of use
- Use of the fuel in a heavy duty diesel engine

According to the study of Sheehan (1998) the summarized overall life cycle air emissions for petroleum diesel are shown in table 3.17. Sheehan (1998) has taken the diesel fuel requirement per brake horsepower per hour of engine as 0.172 kg. In the table 3.17, ‘hydrocarbons (unspecified)’ category does not represent the sum of Non Methane Hydro Carbon (NMHC) and Methane (CH_4). Sheehan (1998) mentioned that they do not exactly know what the original data source for the unspecified category (total hydrocarbons or NMHC) and also that this unspecified category of emissions is ambiguous. According to them this ambiguity is a common problem in life cycle analysis (Sheehan, 1998).

Table 3.17: Life cycle air emissions for petroleum diesel

Pollutant	Quantity (g/ kg)
CH4	1.1793
N2O	0.0394
CO	7.3826
NMHC	0.7643
Hydrocarbons (unspecified)	1.4480
PM10	0.4889
Particulates (Unspecified)	0.7574
SOx	5.3857
NOx	29.1195

Source: Sheehan (1998)

PM10 category represent the particulate matter less than 10 µm. Particulates (unspecified) category do not indicate the size ranges of particulates. But Hung-Lung Chiang (2012) reported that about 80% of the mass fraction of diesel particulate was less than 1.0 µm and 88% of particulate mass was less than 2.5 mm in diesel exhaust. And the percent of particulate mass less than 10 µm and 2.5 mm was 99.4% and 95.1%, respectively (Hung-Lung Chiang, 2012). Therefore the particulates (unspecified) taken as smaller than 10 µm for this life cycle assessment. In Sheehan (1998), higher percentage of PM_{10} emissions was included to diesel fuel consumption. But particulates (unspecified) was collected through the fuel refining, transportation and production processes.

The inventory involved in transportation step is determined by using the data mentioned in table 3.14 (Ministry of Environment, 2011) and the summary of this is shown in Appendix 1.15. The density of diesel fuel is taken as 0.82 kg/l (Ceylon Petroleum Corporation, 2011) and the average yield of medium truck is taken as 3 km/l (table 3.16) in the inventory calculation.

CHAPTER 04 ASSESSMENT OF ENVIRONMENTAL PERFORMANCE OF PADDY PARBOILING PROCESS

The environmental performance assessment carried out in this work looks at the life cycle assessment of the paddy parboiling process adopted in Sri Lanka. This assessment includes definition of the goal and scope, analysis of the life cycle inventory, allocation criteria and assessment of the life cycle impact. The environmental performance of paddy parboiling process is then quantitatively and qualitatively presented.

4.1 Goal and Scope Definition

4.1.1 Goal of the environmental performance assessment

Parboiled paddy production process in Sri Lanka starting from paddy harvesting step to rice cooking step is assessed for environmental performance. The parboiling step in this production process is looked at for three different methods. These three methods named as modern method (see section 2.2.3) with hot soaking and mechanical drying (method 1), modern method with hot soaking sun drying (method 2) and semi modern method (see section 2.2.4) with cold soaking and sun drying (method 3) are assessed and compared.

- ***Method 1***

Method 1 includes paddy parboiling process in modern parboiling method containing hot soaking, steaming and mechanical drying operations. The hot soaking is carried out by soaking the paddy in hot water at 70^0C for four hours. Pressurized steam generated from paddy husk fired boilers is used for steaming process and also to maintain the temperature in hot water used for hot soaking process. Finally paddy is sent through the mechanical dryer (LSU dryer) to reduce the moisture level.

- ***Method 2***

Method 2 includes paddy parboiling with hot soaking, steaming and sun drying operations. The hot soaking is carried out by soaking the paddy in hot water at 70^0C for four hours. In this method also pressurized steam generated from paddy husk fired boilers is used for steaming process and to maintain the temperature in hot water used for hot soaking process. Finally paddy is sun dried.

- ***Method 3***

Method 3 includes paddy parboiling using semi modern parboiling method which includes cold soaking, steaming and sun drying. Water at ambient temperature is used for cold soaking and soaking is carried out for 48 hours. Pressurized steam generated from paddy husk fired boilers is used for steaming process. Finally paddy is sun dried.

4.1.2 Scope of the environmental performance assessment

This LCA study presents estimation of environmental impacts involved in paddy harvesting, threshing, winnowing, subsequent transformation processes done in rice mills and cooking process in Sri Lanka. The environmental impacts of each and every production steps are determined to identify the steps in which the impacts are concentrated within the rice production chain from paddy harvesting to the rice cooking. The influence of the environmental burdens of capital goods that is the production of machinery, roads, irrigation facilities and buildings are excluded in this assessment by considering the very high throughput of work over machine's life (Blengini,2009; Roy, 2006).

4.1.3 Functional unit

In this work the functional unit is taken as "production of one ton of parboiled rice". Parboiled rice is obtained by milling parboiled paddy. One tone of this rice is used in cooking step (see appendix 1.14). Therefore all the impacts are assessed relative to one ton of parboiled rice which is produced and measured next to the milling process.

4.1.4 System boundaries

In this work the parboiled paddy production is looked at in two cases called case 1 and case 2. In case-1, processes from harvesting of paddy to cooking of rice are included in the system boundary (refer figure 4.1). These processes include harvesting, threshing, winnowing, drying harvested paddy, washing, parboiling including soaking, steaming and drying, milling of parboiled paddy and cooking parboiled rice. This case-1 is analyzed for three methods of paddy parboiling as shown in figure 4.1. Therefore case-1 includes assessment and comparison of three different methods from harvesting step to cooking step. In case-1, except the paddy parboiling step the environmental performance of all other steps is the same for all three methods. Therefore in case-2 all these steps are excluded from the system boundary and only the parboiling process including soaking, steaming and drying operations are considered (refer figure 4.2). This assessment and comparison is also done for three paddy parboiling methods.

In both these cases the environmental impacts of the three paddy parboiling methods are assessed. The system boundary for method-1, method-2 and method-3 of the case-1 are shown in the figure 4.1 and the system boundary for method-1, method-2 and method-3 of the case-2 are shown in the figure 4.2. Environmental burdens of transportation involved during production of parboiled rice are not included in system boundary. However an estimated calculation of this environmental burden is given separately in appendix 1.15. The environmental burdens estimated in steps from harvesting to rice cooking consider emissions directly occurring from the respective operation.

Process Flow and System Boundary for case-1

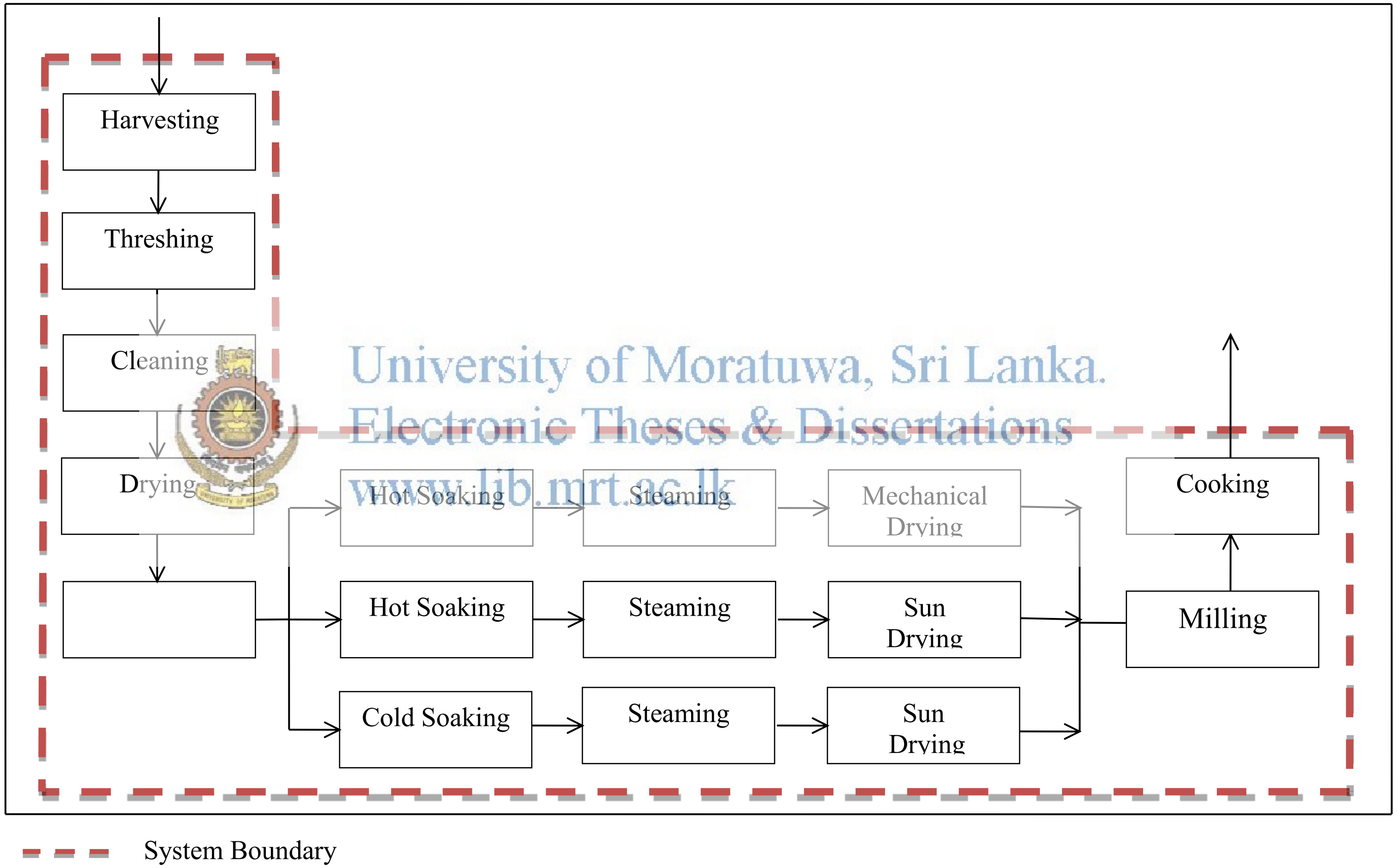

Figure 4.1: Process flow and system boundary for case-1

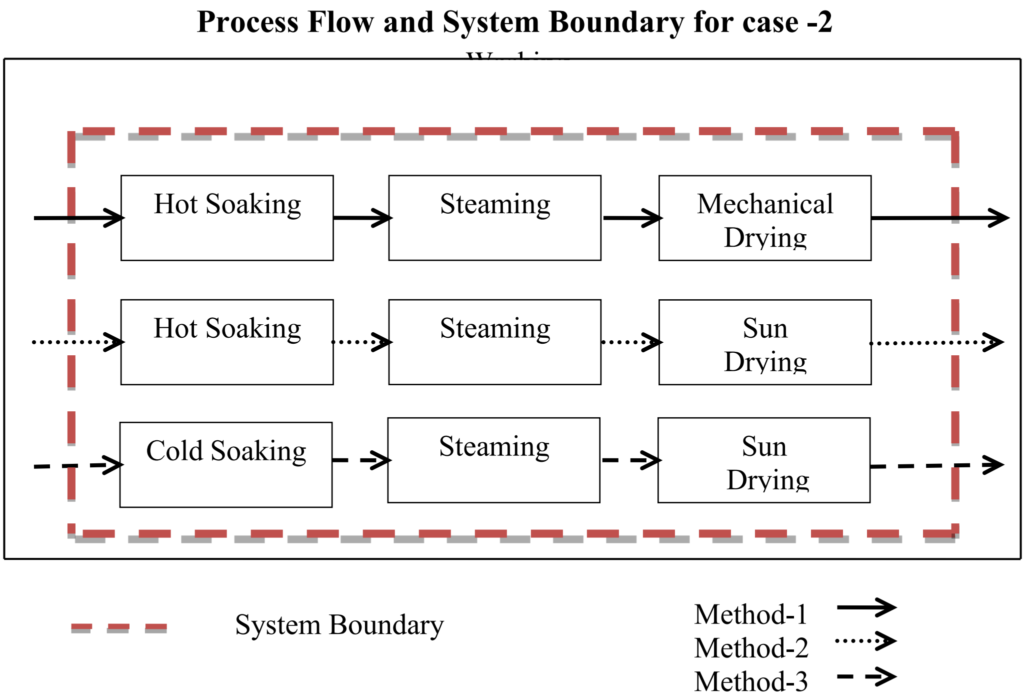

Figure 4.2: Process flow and system boundary for case-2

4.2 Life Cycle Inventory Analysis

In life cycle inventory (LCI) step, all the details of environmental inputs (material and energy) and outputs (water, air emissions, solid emissions etc.) at each stage of the life cycle are analyzed. Inventories of parboiling process (soaking, steaming and drying) for three different parboiling methods as mentioned in section 4.1.1 for one ton of parboiled rice production are estimated separately from harvesting to cooking of rice. The environmental interventions identified from the inventory analysis include gaseous emissions such as CO, CH_4, NOx, CO_2, CH_4, N_2O, NMVOC and TSP. All the calculations are given in Appendix 1 and results and discussion is given in Chapter 5. The data used in estimating the above environmental interventions involved in two system boundary cases described in 4.1.4 are presented in the following section.

The data associated with calculation of the environmental inventories of the parboiled rice production are taken from various literature sources. Harvesting is the first step in the process flow of the system considered in this work. Manual harvesting with sickles is considered because most of the farmers in Sri Lanka still depend on manual harvesting.

Threshing is conducted by low capacity threshers which have a threshing rate of 400 kg/hr with 99.9% efficiency and it is operated with 3.73 kW (5 hp) electric motor (Palipane, 2003; Baruah, 2004). Weight ratio of grain to straw is considered as one is to one (Wijesundara, 1995). Fan coupled with two wheel tractor is used in winnowing method which is the common practice in Sri Lanka. The emissions of diesel fuel combustion shown in table 3.9 published by the Ministry of Environment (2011) are considered to estimate the emissions of diesel engines in both threshing process and winnowing process. These emissions are the diesel fuel burning emissions in Sri Lanka.

Sun drying is the most popular drying method for threshed paddy and this method is considered as the drying method in this work. In washing step, water requirement is taken as about 1.3 times of the weight of paddy (Institute of Post Harvest Technology, 2007). Electric water pump is used to feed the water and the used water is drained off by gravity.

Modern method with hot soaking and mechanical drying (method-1), modern method with hot soaking and sun drying (method-2) and semi modern method with cold soaking and sun drying (method-3) are the different parboiling methods considered in this work . Water requirement for hot soaking is about 1.3 times the weight of paddy and water temperature is maintained at 70^0C for four hours (Institute of Post Harvest Technology, 2007). Hot soaking process requires about 86,000 kCal per one ton of paddy (Wimberly, 1983). In cold soaking water at room temperature is used and soaking is done for 48 hours. Water requirement is nearly 1.3 times the weight of paddy (Institute of Post Harvest Technology, 2007). The soak water is changed every 24 hours which is the general practice in Sri Lanka. Steaming is carried out in small cylindrical iron kettles. Energy requirement of steaming is 25,000 kCal per one ton of paddy (Wimberly, 1983). In method-1, it is considered that LSU dryer type mechanical dryer is used which is the most common type used to dry steamed paddy in Sri Lanka. This mechanical dryer with steam heat exchanger requires energy equal to 137,000 kCal per one ton of paddy (Wimberly, 1983). Modern type rice mill which is considered as the most common commercial mill type used in Sri Lanka is taken for this LCA study. All the machineries and their power requirements of a modern type rice mill are as given table 3.12 (Palipane, 2003). Percentage of husk, bran and rice products of milling paddy are taken as 22%, 7% and 71% (Roy, 2006).

Most popular wood fired semicircular mud stove which has 13% efficiency is used for cooking rice (Perera, 2002). It was assumed that rice needs to be washed twice before cooking as this is the general practice in Sri Lanka and in each wash the same amount of water is used as used in for cooking. Quantity of water required for cooking process is taken as equal to 2.75 times the weight of rice (Billiris, 2012).

Environmental burdens of electricity consumption in all the electric equipment in milling operations and water pumps which are used for soaking and cleaning processes are taken from the table 3.1 (Ministry of Environment, 2011). Ministry of Environment (2011) has determined the GHG and other emissions of electricity generation from diesel oil in Sri Lankan thermal power plants. This includes only the fuel burning emissions and no life cycle emissions of diesel fuel involved has been considered.

Husk fired boilers are used to fulfill the steam requirements in hot soaking, steaming and mechanical drying processes. The average heat value of husk is 3,000 kCal/kg and the husk fired boiler efficiency is 50% (Wimberly, 1983). Emissions of rice husk burning mentioned in the table 3.2 (Chungsangunsit, 2009) are taken as the husk fired boiler emissions.

4.3 Allocation of Environmental Burdens among Rice Products and Byproducts

Rice production is a multifunctional process that generates marketable products and by-products, as well as residuals such as refined rice, broken grains, rice flour, husk and straw. Therefore allocation of environmental impacts among all these products needs to be carried out. In this research, the allocation of burdens to the co-products was done based on their relative economic values as given in table 4.1. Calculation of allocation percentages are given in the Appendix 1.13. A similar method had been adopted by Blengini (2009) in their study of the life cycle of rice. Unit price of the co-products are taken from the Shwetha (2011).

Table 4.1: Impact allocation percentages in parboiled rice production

Product	**Unit price* (Rs.)**	**Weight per one ton of parboiled rice production****	**Value (Rs.)**	**Allocation percentage**
Head rice	26.50	1.00	26.50	94.75 %
Bran	13.00	0.10	1.28	4.58 %
Paddy husk	0.60	0.31	0.19	0.66 %

* Source: Shwetha (2011)

**Refer Appendix 1.13

4.4 Life Cycle Impact Assessment

During impact assessment relative importance of all the environmental burdens identified in inventory analysis are quantified and assessed for their environmental impacts. Selection of impact categories is the first step in impact assessment. After selection of impact categories, the Life Cycle Inventory (LCI) results are subjected to classification and characterization which convert environmental interventions identified in the inventory analysis into an indicator representative of each impact category. Although data related to Sri Lanka are not available to carry out the optional steps of impact assessment, normalization and weighting, the normalization step is attempted with normalization data related to the world.

4.4.1 Selection of impact categories

Based on the inventory analysis results as described in chapter 4 and appendix 1 impact categories depletion of abiotic resources, climate change, human toxicity, photo-oxidant formation, acidification and eutrophication are selected for the LCA study of parboiled rice production in this work. In order to compare, different product systems, same impact categories need to be used (Guinee, et al., 2002). Therefore same impact categories are selected for all three parboiling methods (method-1, method-2 and method-3). All above categories fall under the 'baseline impact category' of the categorization proposed by Guinee et al (2002).

4.4.2 Classification

In the classification step, environmental interventions which can be introduced as flows crossing the boundary between the product system and the environment are assigned to the different pre-selected impact categories (Guinée et al., 2002). Classification of environmental interventions determined by the inventory analysis to relevant selected six impact categories are shown in figure 4.3. There are few environmental inventories identified in the inventory analysis which are not falling under any of the selected impact categories and therefore these inventories are classified into separate impact categories namely solid waste, water consumption, packaging and wastewater with unknown characteristics and are shown in figure 4.4.

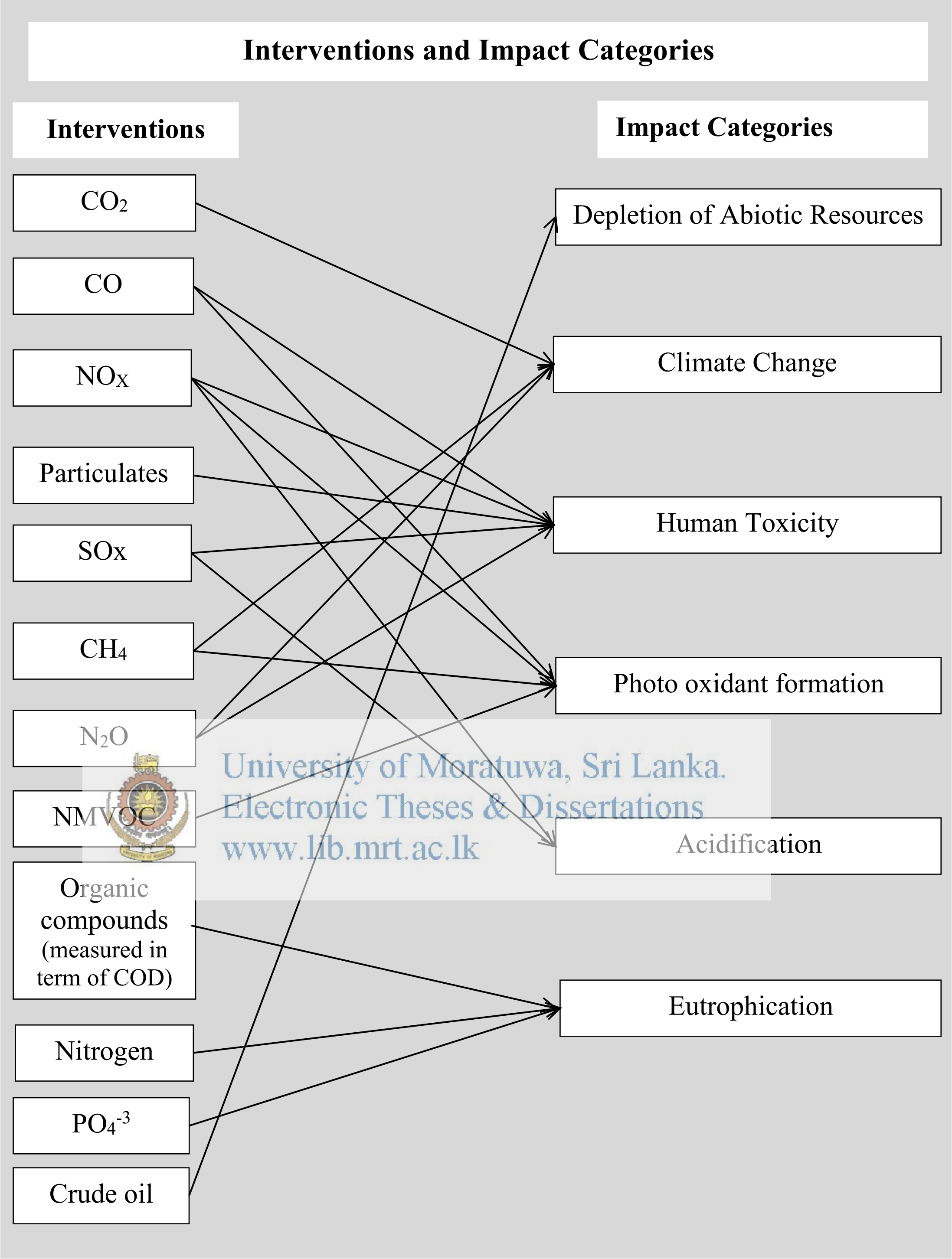

Figure 4.3: Classification of environmental interventions into selected impact categories

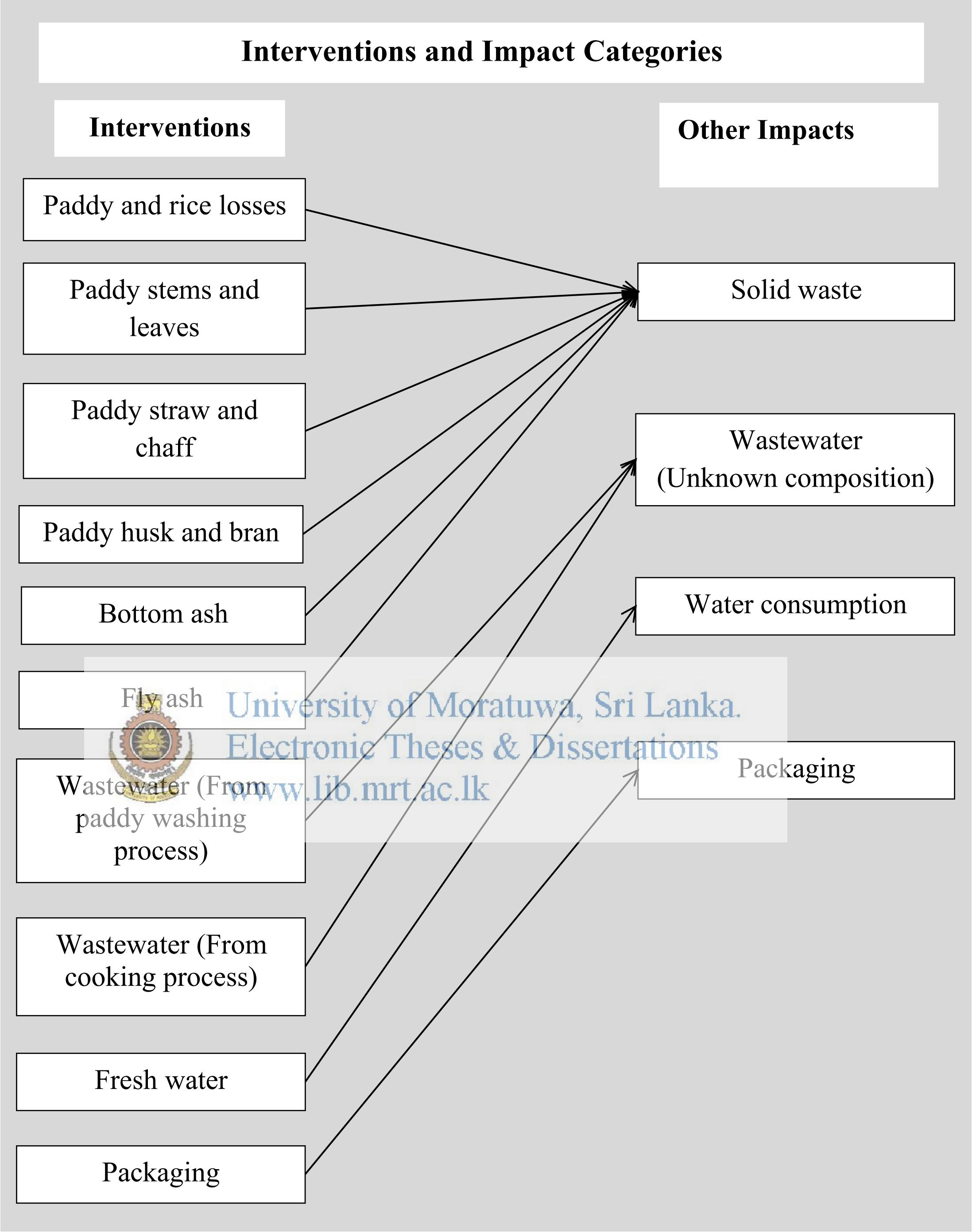

Figure 4.4: Classification of environmental interventions which are not classified under the selected six impact categories

4.4.3 Characterization

In this study the baseline characterization methods developed by Guinée et al. (2002) are considered in characterizing all selected impact categories. Characterization method of each impact category comprises characterization factors for individual interventions. The details of characterization methods proposed by Guinee et al (2002) are shown in Appendix 02. Selected impact categories and characterization factors of each intervention are given in the table 4.2.

Table 4.2: Selected impact categories and characterization factors of each intervention

Impact category	Related intervention	Characterization factors*
Depletion of Abiotic Resources	Diesel (Crude oil)	0.0201 kg antimony eq./kg
Climate Change	Carbon dioxide	1 kg CO_2 eq./kg
	Methane	21 kg CO_2 eq./kg
	Dinitrogen oxide	310 kg CO_2 eq./kg
Human Toxicity	Dust (PM 10)	0.82 kg 1,4- DCB eq./kg
	Sulphur dioxide	0.096 kg 1,4- DCB eq./kg
	Nitrogen dioxide	1.2 kg 1,4- DCB eq./kg
Photo oxidant formation	Carbon monoxide	0.027 kg C_2H_4 eq./kg
	Methane	0.006 kg C_2H_4 eq./kg
	Nitrogen dioxide	0.028 kg C_2H_4 eq./kg
	Ethanol	1 kg C_2H_4 eq./kg
Acidification	Nitrogen oxides (as NO_2)	0.5 kg SO2 eq. /kg
	Sulphur dioxide	1.2 kg SO2 eq. /kg
Eutrophication	Nitrogen	0.42 kg PO_4^{-3} eq. /kg
	Phosphate	1 kg PO_4^{-3} eq. /kg
	COD	0.022 kg PO_4^{-3} eq. /kg

*Source : Guinee et. al (2002)

Out of the environmental interventions identified (see Appendix 1) for non methane volatile organic compounds (NMVOC) the determination of characterization factors were not possible as the composition of NMVOC is not known (Ministry of Environment, 2011; Sheehan,1998). Therefore in this work the photo oxidant formation impact influenced by NMVOC emission is assumed to be equivalent to the photo oxidant formation impact of ethanol and calculated by using characterization factor of ethanol. Characterization factor of ethanol is available in literature and is equal to one (Guinee, et al., 2002).

Qualitatively classified environmental interventions are quantified in characterization step in terms of a common unit and then the calculated impacts of different types of environmental inventories are aggregated by summing up into a single score in each impact category. The m_i value used in the characterization step is the environmental burdens (emission quantity of *i* substance in kg) calculated in the inventory analysis as shown in Appendix 1. An example calculation for climate change impact category for the threshing operation is as follows.

- **Calculation of the climate change impact of threshing process**

Climate change impact of CO_2 emission = $GWP_{a,i} \times m_i$
= 1 kg CO_2 eq./kg x 3.7638 kg
= 3.7638 kg CO_2 eq.

Climate change impact of CH_4 emission = $GWP_{a,i} \times m_i$
= 21 kgCO_2 eq./kg x 2.49×10^{-4} kg
= 0.0052 kg CO_2 eq.

Climate change impact of N_2O emission = $GWP_{a,i} \times m_i$
= 310 kgCO_2 eq./kg x 2.37×10^{-5} kg
= 0.0073 kg CO_2 eq.

According to the allocation criteria described in section 4.3 these impacts need to be adjusted by allocating the environmental burdens among the products and byproducts produced in the process of producing parboiled rice. Therefore all the impact values calculated in the impact assessment before milling process need to be multiplied by impact allocation percentage of rice product which is equal to 94.75% in this work (see table 4.1). Therefore the allocation of climate change impact to rice product is as follows.

Climate change impact of CO_2 emission = 3.7638 kgCO_2 eq. x Allocation percentage
= 3.7638 kg CO_2 eq. x 94.75%
= 3.566 kg CO_2 eq.
Climate change impact of CH_4 emission = 0.0052 kgCO_2 eq. x Allocation percentage
= 0.0052 kg CO_2 eq. x 94.75%
= 0.005 kg CO_2 eq.
Climate change impact of N_2O emission = 0.0073 kgCO_2 eq. x Allocation percentage
= 0.0073 kg CO_2 eq. x 94.75%
= 0.007 kg CO_2 eq.

Therefore the total climate change impact of threshing process can be calculated by summing above calculated values of climate change impact of each emission.

Total climate change impact of threshing = (3.566 + 0.005 + 0.007) kgCO_2eq.
= 3.578 kg CO_2 eq.

The details of calculation of other impact categories of each processing step are shown in Appendix 03.

4.4.4 Normalization

As mentioned in the Chapter 2, the goal of the normalization is to establish a common reference to facilitate comparison of different environmental impacts and it helps to show to what extent an impact category has a significant contribution to the overall environmental problem. There are many normalization methods that have been developed and the selection of the “Normal” values depends on the goal of the study. The normalization results of environmental interventions are calculated using following equation (Guinee, et al., 2002).

Normalized indictor result$_{category}$ = Indictor result$_{category}$ / Indictor result$_{category, reference}$

Indictor result $_{category, reference}$	= Normalization factor for impact category and reference system (kg.yr^{-1}. capita^{-1}).
Normalized indicator result$_{category}$	= Normalized indicator result for impact category (yr.capita)
Indicator result $_{category}$	= Indicator result for impact category (kg)

4.4.4.1 Normalization based on normalization factors for the world

The normalization factors with the annual per capita extent for world (1990) as mentioned in Guinee (2002) are used for this LCA study and are shown in table 4.3.

Table 4.3: Normalization factors with annual per capita extent for world, 1990

Impact Category	Normalization factors	
Depletion of Abiotic Resources	30.1	kg antimony eq.yr^{-1}.capita^{-1}
Climate Change	8460	kg CO_2 eq.yr^{-1}.capita^{-1}
Human Toxicity	10900	kg 1,4- DCB eq.yr^{-1}·capita^{-1}
Photo oxidant formation	20.3	kg C_2H_2 eq.yr^{-1}·capita^{-1}
Acidification	59.5	kg SO_2 eq. yr^{-1}.capita^{-1}
Eutrophication	25.1	kg PO_4^{-3} eq. yr^{-1}.capita^{-1}

Source: Guinee et al. (2002)

An example calculation is shown for normalization for impact of depletion of abiotic resources for case-1 (method-1) where the characterized impact value is 0.195 kg antinomy equivalents.

Normalized result= Indictor result $_{category}$ / Indictor result $_{category, reference}$

= 0.195 kg antimony eq. / 30.1 kg antimony eq.yr^{-1}.capita^{-1}

= <u>0.006 yr.capita</u>

Similarly the normalized results of all environmental impacts of one ton of parboiled rice production (case-1) and parboiling processes (case-2) are shown in Appendix-03.

4.4.4.2 Normalization based on normalization factors for Sri Lanka

Normalization factors related to Sri Lanka except for climate change are not yet being estimated. The total GHG emission of Sri Lanka in year 2000 was 12,588.96 x 10^6 kg CO_2 eq. and per capita GHG emission of Sri Lanka in 2000 was 6.64 x 10^2 kg CO_2 eq. capita $^{-1}$ (Ministry of Environment, 2011).

An example calculation is shown for normalization for impact of climate change for case-1 (method-1) where the characterized impact value is 356.310 kg CO_2 equivalents.

Normalized result= Indictor result $_{\text{category}}$ / Indictor result $_{\text{category, reference}}$

$$= 356.310 \text{ kg } CO_2 \text{ eq.} / 6.64 \times 10^{2} \text{ kg } CO_2 \text{ eq.yr}^{-1}\text{.capita}^{-1}$$

$$= \underline{\underline{0.537 \text{ yr.capita}}}$$

Similarly the normalized results of climate change impact of one ton of parboiled rice production (case-1) and parboiling processes (case-2) are calculated in Appendix-03.

CHAPTER 05 RESULTS AND DISCUSSION

In the process of environmental assessment of paddy parboiling from harvesting step to rice cooking step using the life cycle assessment approach, initially the study boundary was defined and the inventories of inputs and outputs were estimated. These inventories determined along with environmental impacts resulting from them, estimated quantitatively are presented in following sections.

5.1 Inventories of Parboiled Rice Production

Inventories of one ton of parboiled rice production in case-1 for method-1, method-2 and method-3 are shown in the table 5.1. Wastewater unspecified includes wastewater from paddy washing process carried out before soaking process and the wastewater from rice washing process carried out before cooking. Since its characteristics are unknown it is referred to as unspecified wastewater in this work. Inventories of parboiling process including steps soaking, steaming and drying for the three different parboiling methods mentioned in case-2 are shown in the table 5.2.

The major inputs of the parboiled rice production in case-1 are diesel, water and wood. Diesel fuel is used for threshing, winnowing and also for electricity generation which is used in water pumping and milling process. Threshing, winnowing and milling are similar in rice production system. Only the water pumping requirements are varying in between hot soaking and cold soaking and therefore diesel consumption is higher in method-3 where cold soaking requires to pump a high water quantity than in hot soaking. Water and diesel fuel consumption in hot soaking and cold soaking processes can be identified from table 5.2.

Table 5.1: Inventories of one ton of parboiled rice production in case-1

Major inventories per one ton of parboiled rice production	Unit	Parboiling Methods: steps from harvesting to rice cooking		
		Method-1	Method-2	Method-3
Inputs				
Diesel	liters	11.76	11.76	11.97
Water	m^3	11.84	11.84	13.64
Wood	kg	1,779.69	1,779.69	1,779.69
Outputs				
Solid waste				
Paddy and rice waste	kg	107.66	107.66	107.66
Straw	kg	1,484.60	1,484.60	1,484.60
Husk	kg	37.61	188.13	267.34
Bran	kg	93.42	93.42	93.42
Fly ash	kg	37.57	15.48	3.85
Bottom ash from combustion	kg	7.78	3.20	0.80
Emissions to air				
CO	kg	134.00	132.85	133.46
CH_4	kg	15.47	15.47	15.47
NO_x	kg	2.46	2.28	2.38
CO_2	kg	1,876.78	1,876.78	1,996.65
SO_2	kg	0.88	0.82	0.85
N_2O	kg	0.00	0.00	0.00
NMVOC	kg	0.01	0.01	0.01
TSP	kg	15.69	15.67	15.66
Emissions to water with known characteristics				
Wastewater (specified)	m^3	1.60	1.60	3.40
N	kg	0.02	0.02	0.04
PO_4^{-3}	kg	0.08	0.08	0.18
COD	kg	9.61	9.61	17.33
Wastewater (characteristics unknown)				
Waste water (Unspecified)	m^3	7.30	7.30	7.30
Packaging (PP)	kg	6.28	6.28	6.28

Table 5.2: Inventories of parboiling processes of case-2

Major Inventories per functional unit	**Unit**	**Parboiling Methods (soaking, steaming and drying)**		
		Method-1	**Method-2**	**Method-3**
Inputs				
Diesel	liters	0.03	0.03	0.18
Water	m^3	1.80	1.80	3.59
Rice Husk	kg	255.98	105.46	26.26
Outputs				
Solid waste				
Paddy and rice waste	kg	27.63	27.63	27.63
Fly ash	kg	37.57	15.48	3.85
Bottom ash from combustion	kg	7.78	3.20	0.80
Emissions to air				
CO	kg	1.96	0.81	0.20
CH_4	kg	0.00	0.00	0.00
NOx	kg	0.30	0.12	0.03
CO_2	kg	365.69	150.84	38.20
CH_4	kg	0.00	0.00	0.00
N_2O	kg	0.00	0.00	0.00
NMVOC	kg	0.00	0.00	0.00
TSP	kg	14.86	14.85	14.84
Emission to water with known characteristics				
Waste water (specified)	m^3	1.60	1.60	3.40
N	kg	0.02	0.02	0.04
PO_4^{-3}	kg	0.08	0.08	0.18
COD	kg	9.61	9.61	17.33

Paddy husk which can be considered as solid waste in milling process are used in parboiling process as bio mass fuel to generate heat energy in husk fired boilers. Therefore paddy husk is taken as an input inventory in parboiling process. The husk consumption varies with steam requirement in parboiling process. Hot soaking, steaming and mechanical drying require heat energy from boiler. Method-1 of case-2 has the highest steam consumption with hot soaking, steaming and mechanical drying. Method 2 has lower steam consumption than that in method-1 because it practices sun drying instead of mechanical drying. Method-3 has the lowest energy consumption due to cold soaking and sun drying. Steam consumptions for paddy steaming processes in all three methods are similar. Wood is used as an energy source for cooking process which is similar for all three methods in case-1.

Output inventories of parboiled rice production are categorized under solid waste, air emissions, waste water (specified), wastewater (unspecified) and packaging. All the solid wastes produced other than paddy husk which is used as energy sources for parboiling process are similar for all three parboiling methods. The rice husk remained after milling operation in rice mills, are dumped in open areas as solid waste. This can result in waste disposal problems. Rice straw contains great amounts of plant nutrients and therefore it can be added back to the field. Some farmers burn the straw mainly when there is no other way of disposal. Field burning of rice straw is an inexpensive method of crop residue disposal and it is practiced in many parts of Sri Lanka. This activity emits greenhouse gases and other air pollutants such as particles, inorganic and organic gases to the environment (Oanh, 2011). Small amount of rice straw is used as feed for cattle, raw material for packaging, paper and paperboards manufacturing processes in Sri Lanka. Blengini (2009) excluded rice straw in his study of LCA and allocated no environmental burdens due to its insignificant market value. In this study rice straw and excess rice husk are considered as solid wastes that has no environmental burdens and therefore allocated no impacts other than considering it as solid waste.

Inventories of emissions include emissions from diesel fuel, rice husk and wood combustion in parboiled rice production in case-1 and in the case 2 emissions from rice husk and diesel combustions of parboiling processes. The emissions of N_2O and NMVOC are insignificant in both case-1 and case-2 and the emission of CH_4 is insignificant only in case-2. The main CH_4 contributor in parboiled rice production of case-1 is wood combustion in cooking step. Diesel combustion is the main contributor of CH_4 emission in parboiling processes of case-2 and it is a negligible value compared to case 1. Husk fired boiler emissions and wastes are CO, CH_4, NO_X, CO_2, N_2O, NMVOC and TSP. These emissions vary according to the heat energy generation in the boiler. Method-1 has the highest energy consumption and it has resulted in the highest environmental emissions. Method-3 shows the lowest emissions which consumes the lowest heat energy quantity. Fly ash and bottom ash of husk fired boilers are considered as solid waste (Chungsangunsit, 2009) and are included under impact of solid wastes. Quantity of CO_2 emission of parboiled rice production in case-1 has a very high value compared to other air emissions as CO, CH_4, NO_X, SO_2, N_2O and NMVOC. In case-1 the major CO_2 contributor is from fuel wood burning in cooking process. The major CO_2 contributor of parboiling processes in case-2 is paddy husk combustion. It is assumed that the CO_2 emissions of rice husk and fuel wood burning quantified in the inventory analysis are re-absorbed by the biomass carbon cycle. Therefore its environmental impacts are neglected assuming that the CO_2 emissions during burning are balanced by consumption of CO_2 in crop growth (Blengini, 2009). Shackley (2012) has also made a similar assumption equating the quantity of CO_2 emission arising from the biotic or abiotic conversion of organic carbon to quantity taken up by plant photosynthesis in subsequent growth cycles in his study of rice-husk gasification in Cambodia.

The wastewater discharges from soaking processes are having known characteristics such as N, PO_4^{-3} and COD, and therefore considered as ‘specified’ in the inventory estimation. Characteristics of effluents of paddy washing water and rice washing water are assumed to have negligible environmental impacts. The data on characteristic values of COD, N, and $PO_4^{-3}$of paddy soaked wastewater show higher values in cold soaked wastewater compared to wastewater from hot soaking method.

The quantities of packaging are similar in all three methods. The average weight of a polypropylene bag used to pack 1kg of parboiled rice available in the market is about 6.28 g. Therefore the calculated polypropylene bags requirement per one ton of parboiled rice is 6.28 kg.

Transportation of the paddy and rice also gives rise to considerable burdens on the environment. The transportation distances vary according to the location of paddy field, rice mills, markets and consumers. As the distances are different in each and every case one case of transportation that is the environmental emissions of transportation from Anuradhapura to Colombo are considered in estimating the environmental burdens in this work. However, these environmental emissions are not considered and included in the impact assessment step because these emissions do not represent an average value for paddy and rice transportation in Sri Lanka.

The distance between Anuradhapura and Colombo is 206 km and rice transportation of this distance is usually done by medium size trucks which require about 68.66 liters of diesel fuel. The environmental emissions of 68.66 liters of diesel are shown in table 5.3. Calculations of transportation step are given in Appendix 1.15.

Table 5.3: Environmental burdens or emissions of paddy transportation from Colombo to Anuradhapura by medium size truck (For 206 km)

Emissions	**Quantity (g/km) (see table 3.14)**	**Quantity (kg) for 206km**
CH_4	0.086	0.018
N_2O	0.010	0.002
CO	17.614	3.628
CO_2	1,291.667	266.057
NMVOC	3.521	0.725
SO_X	2.439	0.502
NO_X	14.093	2.903

5.2 Environmental Impact Assessment of parboiled paddy production

5.2.1 Classification

From the inventory analysis the environmental interventions were identified and the relevant impact categories were selected. The selected impact categories are depletion of abiotic resources, climate change, human toxicity, photo-oxidant formation, acidification and eutrophication. The environmental burdens were then classified to selected impact categories shown in figure 4.3.

Consumption of crude oil is classified as an impact falling under the depletion of abiotic resources. Although river water resource is categorized under abiotic resources, it is considered as a resource regenerated constantly. Therefore the impact of consumption of this kind of resources is not aggregated into the results of depletion of abiotic resources. On the other hand fossil fuel is depleted with consumption and is not regenerated within human life time (Guinee, et al., 2002).

Air emissions can cause climate change, human toxicity, photo oxidant formation and acidification impacts. Pollutants in the wastewater such as the organic matters, N and P cause eutrophication. Some emissions can cause more than one environmental impact. For example emissions of CO, NO_X, SO_X, CH_4 and N_2O are contributed to more than one impact category. Emissions of CO can result in photo oxidant formation and human toxicity and NO_X can make human toxicity, photo oxidant formation and also acidification impact. Emissions of SO_X contribute to human toxicity and acidification while CH_4 contribute to climate change and photo oxidant formation. Photo oxidant formation is caused by CO, CH_4, NMVOC and NO_X. These emissions can be identified as “emissions with parallel impacts”. In this work although these emissions may theoretically contribute to more than one impact category it is assumed that they contribute only to one impact category.

Other environmental burdens which are not classified under the six selected impact categories are classified under impact categories solid waste, wastewater generation with unknown composition, packaging and water consumption and they are shown in figure 4.4.

5.2.2 Characterization of impact categories

Classified impacts are then characterized as described in 4.3.3 and the results of these characterized environmental impacts of parboiled rice production are shown in the table 5.4. Other environmental burdens which are not classified under selected impact categories are included in the table 5.5 separately.

Table 5.4: Characterization of impact categories of one ton of parboiled rice production

Impact category	Unit	Harvesting	Threshing	Winnowing	Sun Drying	Washing	Cold soaking	Hot soaking	Steaming	Sun drying	Mech. Drying	Milling	Cooking
Depletion of Abiotic Resources	kg antimony eq.	-	0.023	0.004	-	0.001	0.003	0.000	-	-	-	0.167	-
Climate Change	kg CO_2 eq.	-	3.578	0.572	-	0.241	0.481	0.072	0.000	-	0.000	27.071	324.776
Human Toxicity	kg 1,4- DCB eq.	-	0.047	0.008	-	0.001	0.002	0.120	0.040	-	0.228	0.093	15.587
Photo oxidant formation	kg C_2H_4 eq.	-	0.012	0.002	-	0.000	0.000	0.019	0.006	-	0.036	0.004	3.751
Acidification	kg SO_2 eq.	-	0.028	0.004	-	0.001	0.002	0.080	0.026	-	0.151	0.098	2.052
Eutrophication	kg PO_4^{-3} eq.	-	-	-	-	-	0.576	0.299	0.000	-	-	-	-

Table 5.5: Other environmental burdens of one ton of parboiled rice production

Impact category	Unit	Harvesting	Threshing	Winnowing	Sun Drying	Washing	Cold soaking	Hot soaking	Steaming	Sun drying	Mech. Drying	Milling	Cooking
Solid Waste	kg	30.298	1,514.294	0.291	0.415	-	-	14.030	4.651	27.629	54.293	406.344	-
Waste water *	Tons	-	-	-	-	1.796	-	-	-	-	-	-	5.500
Water consumption	m^3	-	-	-	-	1.796	3.592	1.796	-	-	-	-	8.250

*Waste water with unknown composition.

Harvesting is done manually and therefore it causes no significant impact on environment. Further, the environmental impacts of sun drying process can also be considered as insignificant. Depletion of abiotic resources caused by diesel consumption is highest in milling process which requires the highest quantity of electricity energy which is generated using diesel. Threshing, winnowing, paddy washing, cold soaking and hot soaking also contribute to the impact of abiotic resources depletion. Climate change impact is observed highest in cooking process. The CO_2 emission of burning biomass is excluded by considering the assumption on biomass replacement (Blengini, 2009) and therefore calculated climate change effect of cooking is only caused by CH_4 emission of fuel wood burning. Other than cooking, the processes of threshing, winnowing, paddy washing, cold soaking, hot soaking and milling also contribute to climate change impact. Highest impacts on the climate change, human toxicity, photo oxidant formation and acidification are due to the cooking step. Threshing, winnowing, hot soaking, steaming, mechanical drying and milling processes also contribute to photo oxidant formation. Impact of acidification is caused by threshing, winnowing, washing, cold soaking, hot soaking, steaming, mechanical drying, milling and cooking processes. Eutrophication impact is caused by emissions of cold soaking and hot soaking processes and the highest impact is observed in the cold soaking operation.

Solid waste, waste water with unknown composition, water consumption are mentioned as other environmental burdens of parboiled rice production which are not classified under selected impact categories. Solid waste of parboiled rice production is mainly comprised with bio mass of waste paddy and rice, paddy husk and paddy straw, fly ash and bottom ash. They can be recognized as non-toxic. Highest weight of solid waste is observed in threshing process where rice straw is the major waste. Waste water emissions from rice and paddy cleaning processes are referred to as unspecified emissions due to unknown effluent composition. The highest water requirement is observed in the cooking process. Other than in cooking process, water is required in paddy washing and soaking processes too.

Summary of the characterized environmental impacts of one ton of parboiled rice production for case-1 that is from harvesting step to rice cooking step is shown in the table 5.6.

Table 5.6: Characterized impacts of one ton of parboiled rice production in case-1

Impact Categories	Method-1	Method-2	Method-3	Units
Depletion of Abiotic Resources	0.195	0.195	0.197	kg antimony eq.
Climate Change	356.310	356.310	356.720	kg CO_2 eq.
Human Toxicity	16.124	15.896	15.777	kg 1,4- DCB eq.
Photo oxidant formation	3.831	3.795	3.776	kg C_2H_4 eq.
Acidification	2.440	2.289	2.211	kg SO_2 eq.
Eutrophication	0.299	0.299	0.576	kg PO_4^{-3} eq.

Other environmental burdens of parboiled rice production (case-1) which are not classified under selected impact categories are shown in the table 5.7.

Table 5.7: Other environmental burdens of one ton of parboiled rice production (case-1) which are not classified under selected impact categories

Inventories	Method-1	Method-2	Method-3	Units
Solid Waste	1,768.631	1,892.491	1,957.665	kg
Waste water (Unknown composition)	7.296	7.296	7.296	m^3
Water consumption	11.842	11.842	13.638	m^3
Packaging (PP)	6.28	6.28	6.28	kg

Environmental impacts of parboiling processes and other environmental burdens which are not classified under selected impact categories of case-2 are shown in the table 5.8 and table 5.9.

Table 5.8 Environmental impacts of parboiling processes (case-2) per functional unit

Impact Categories	**Method-1**	**Method-2**	**Method-3**	**Units**
Depletion of Abiotic Resources	0.000	0.000	0.003	kg antimony eq.
Climate Change	0.072	0.072	0.481	kg CO_2 eq.
Human Toxicity	0.389	0.160	0.041	kg 1,4- DCB eq.
Photo oxidant formation	0.061	0.025	0.006	kg C_2H_4 eq.
Acidification	0.258	0.106	0.028	kg SO_2 eq.
Eutrophication	0.299	0.299	0.576	kg PO_4^{-3} eq.

Table 5.9: Other environmental burdens of parboiling processes (case-2) per functional unit which are not classified under selected impact categories

Inventories	**Method-1**	**Method-2**	**Method-3**	**Units**
Solid Waste	72.975	46.311	32.280	kg
Water consumption	1.796	1.796	3.592	m^3

In case-2, environmental impacts of human toxicity, photo oxidant formation and acidification are higher in modern method (method-1) which has a high energy consumption for hot soaking and mechanical drying. Climate change impact shows a higher value in method-3 due to the emissions from burning of diesel which is used in water pumping operation. Depletion of abiotic resources caused by diesel consumption which needs to energize the water pumps is increased with higher water requirement for cold soaking in method-3. Eutrophication impact is higher in semi modern method (method-3) due to higher P and N content in wastewater resulting from cold soaking process.

5.2.3 Normalization of environmental impacts

5.2.3.1 Normalization using factors related to the world

Normalized results using normalization factors related to the world for environmental impacts of parboiled rice production (case-1) per functional unit are given in the figure 5.1.

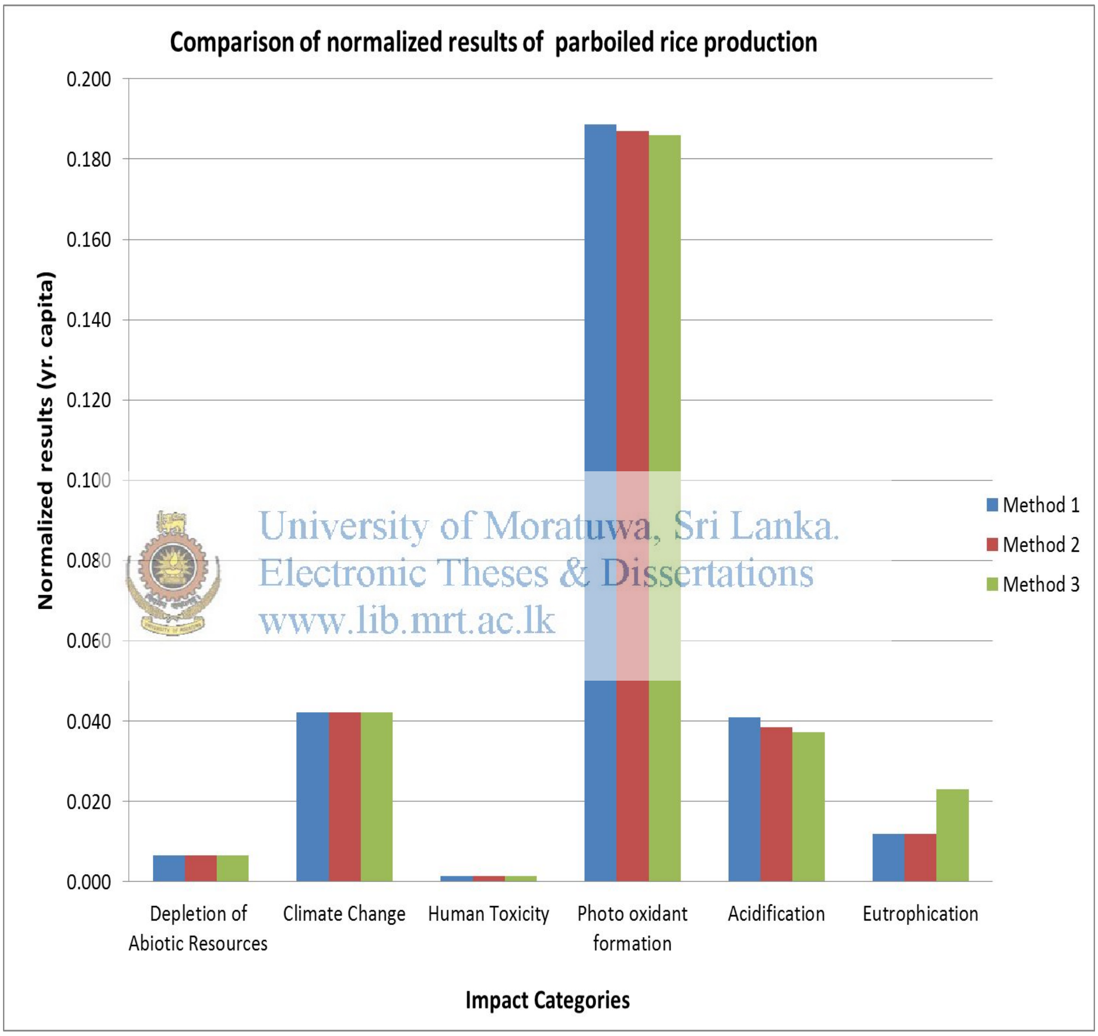

Figure 5.1: Normalized results of parboiled rice production in case-1 per functional unit

Photo oxidant formation gives the highest impact of parboiled rice production (case-1). Major contributor of photo oxidant formation is fuel wood combustion in cooking step. Climate change and acidification also give significant contribution to the impact on the environment. Normalized values of human toxicity gives negligible impact compared to other impacts. Although human toxicity and climate change show significantly high impact values after characterization (refer table 5.6), it has high normalization factors comparing to other impacts and therefore normalized values have become small. According to the Guinee et al. (2002) human toxicity has the highest normalization factor among selected impacts. All environmental impacts other than eutrophication are showing very little variation among three parboiling methods mentioned in the case-1. The reason for this result is that there are many steps such as harvesting, threshing, winnowing, washing, milling and cooking which are equal to three rice processing methods and only the parboiling process steps are varying among them. The following figure 5.2 represents the variation of normalized results based on world normalization factors of impact categories among the parboiling methods in case-2.

According to the normalized results in case-2, there is a huge increment in the value of eutrophication impact with respect to other impacts. The normalized result of depletion of abiotic depletion, climate change and human toxicity impacts of parboiling processes have insignificant values with comparison to eutrophication impact. The eutrophication impact is highest in method-3 and the photo oxidant formation and acidification impacts are highest in method-1.

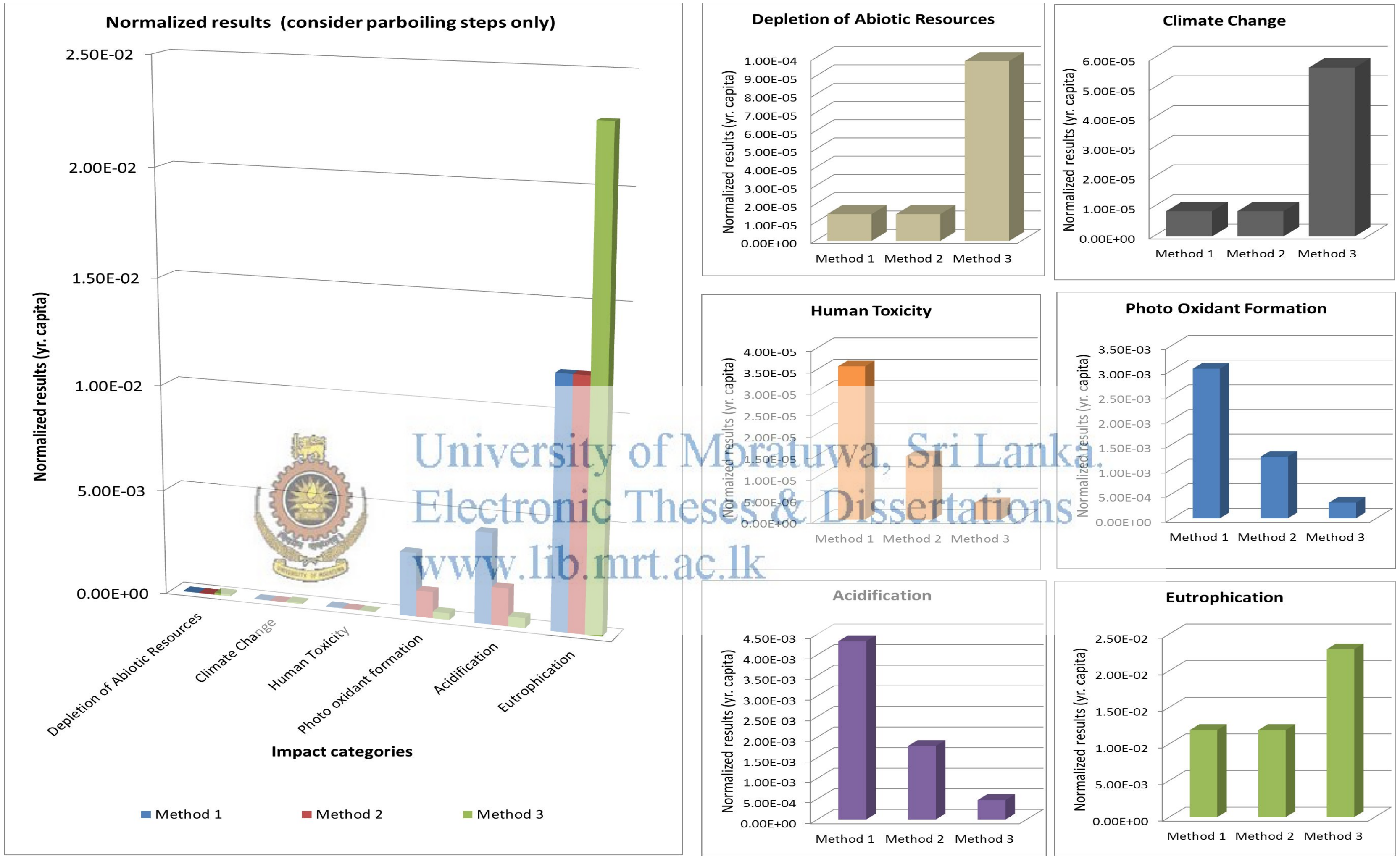

Figure 5.2: Normalized results of parboiling processes in case-2

5.2.3.2 Climate change impact normalized based on normalization factors related to Sri Lanka

The normalized results for climate change impact per one ton of parboiled rice production in case 1 and case 2 are given in following figure 5.3 and figure 5.4 respectively.

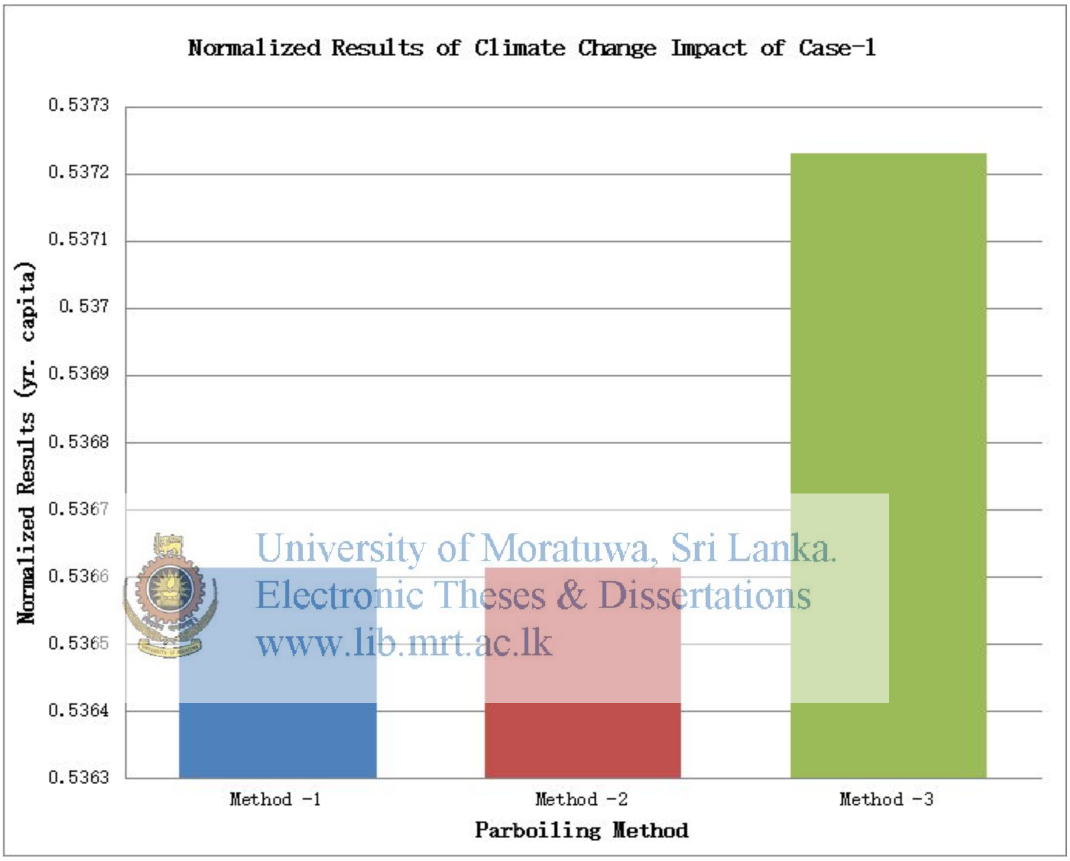

Figure 5.3: Normalized results of climate change impact of case-1 per functional unit (Normalization factor is based on Sri Lanka)

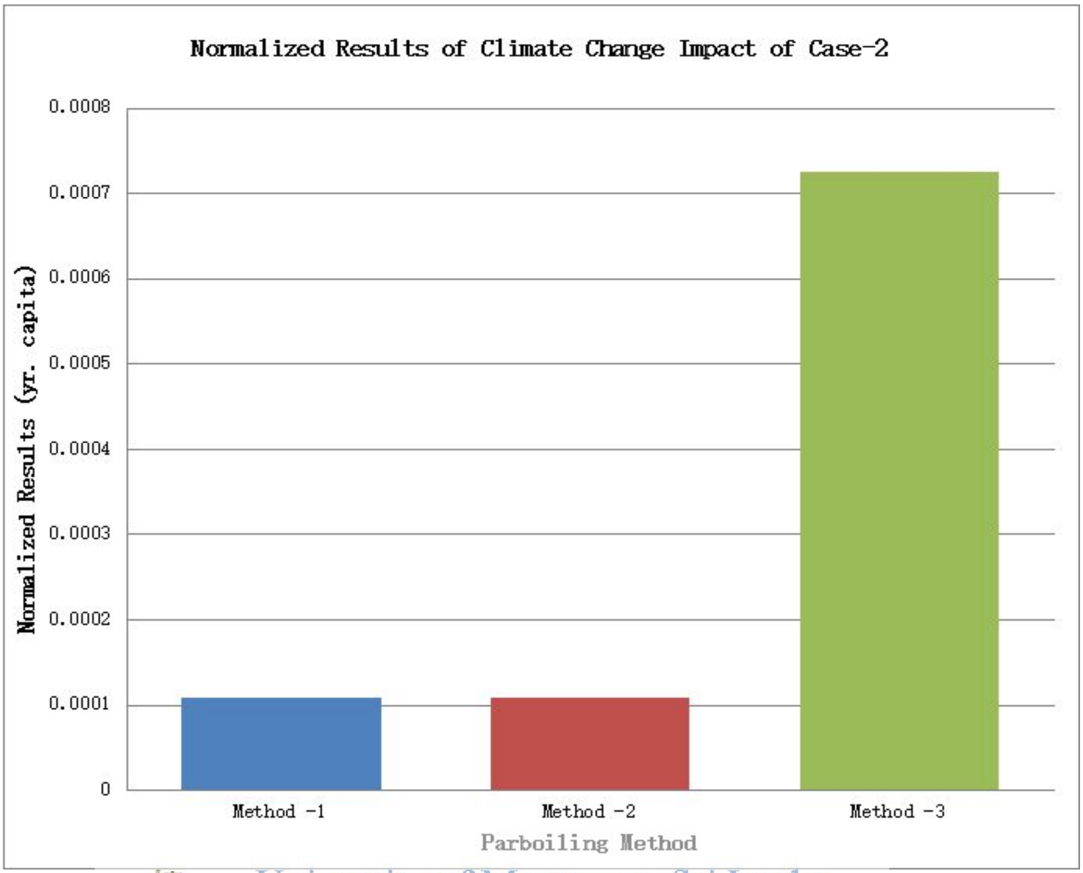

Figure 5.4: Normalized results of climate change impact of case-2 per functional unit (Normalization factor is based on Sri Lanka)

The normalized results of climate change impact based on normalizing factors related to world and Sri Lanka shown in figure 5.1, figure 5.2, figure 5.3 and figure 5.4 for both case-1 and case-2, show a difference in the magnitude of normalized results of world and Sri Lanka. This is due to the low value of the normalization factor of climate change impact in Sri Lanka. This shows that emissions of the greenhouse gasses in the world are very much higher compared to the greenhouse gas emissions in Sri Lanka. This may be true for other emissions as well. Therefore normalized results using data related to world may not represent results closer to the actual situation in Sri Lanka.

5.3 Comparison with Environmental Assessments of Parboiled Paddy Production in Literature

Roy (2007) measured CO_2 emissions of the life cycle of parboiled rice production from 'Vessel' method and 'Medium boiler' method which are practiced in Bangladesh. 'Vessel' method is a direct heating method of parboiling used in household level. A clay-pot is used for soaking. One or two vessels are being used in pre-steaming and steaming processes. 'Medium boiler' method is used for commercial purposes. Two sets of two conical hoppers are used for pre-steaming and steaming and these sets are connected with a boiler. In this process, pre-steaming and steaming starts at a steam pressure of 245 kNm^{-2} and steam is delivered to the paddy within the pressure range of 116–245 kNm^{-2}.

According to the Roy (2007), the system boundary of the life cycle of parboiled rice production of 'Vessel' method and 'Medium boiler' method includes parboiling process with pre-steaming, soaking and steaming. The parboiled paddy drying step has not been included in their system boundary. Other than parboiling process the system boundary includes dehusking, milling and cooking steps. The resulted CO_2 emissions of the 'Vessel' method and 'Medium boiler' method were nearly 1310 kg and 1210 kg per one ton of parboiled rice. In this study, CO_2 emissions of the life cycle of parboiled rice production from method-1, method-2 and method-3 was 2,344.06 kg, 2,117.30 kg and 1998.41 kg per one ton of parboiled rice after milling respectively. Although the values of CO_2 emissions of this study and Roy (2007) are different the order of the magnitude is the same. The differences in the results may be due to the differences of selected parboiling methods and specially the differences between system boundaries. Some processes which are considered in the system boundary of this study have not been considered in the system boundary of the study of Roy (2007) such as threshing, winnowing, washing and drying.

CHAPTER 06 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Environmental loads of rice production vary depending on the method of production employed. Although the parboiling process increases the milling qualities and provides more nutritious products, it consumes more energy and materials and cause environmental impacts. When the energy consumptions of processes are high, the environmental emissions and related environmental damages are also high.

Based on inventory analysis and characterized impact category results depletion of abiotic resources is higher in semi modern method (method-3) where cold soaking required more diesel fuel for water pumping process. Climate change is higher in semi modern method (method-3) due to higher diesel fuel burning emissions caused by water pumping process in cold soaking. Human toxicity, photo oxidant formation and acidification are higher in modern method (method-1) due to high husk fired boiler emissions caused by high steam consumption. Eutrophication impact is higher in semi modern method (method-3) where cold soaking of paddy is done which results in wastewater containing higher P and N contents.

Water consumption is higher in case-1 where the system boundary contains larger number of processing steps for all three methods. In both cases, method 3 shows higher water consumption. Here the paddy parboiling process consumes about 26% of the total water consumed in case-2 where operations from harvesting paddy step to cooking step are considered.

The solid waste generated in case-1 is very much higher compared to solid waste generated from the paddy parboiling process (case-2). The solid waste generated from parboiling methods is about 1-5% of the total solid wastes generated from case-1 where operations from harvesting paddy to cooking step are considered.

The environmental impact assessment considering life cycle of the parboiled paddy production from harvesting step to rice cooking step show higher environmental impacts in all categories considered in this work. The eutrophication impact was the same in both, case-1 and case-2. The paddy parboiling step is the only step in the parboiled paddy production process that contributes to eutrophication impact.

6.2 Recommendations for future work

- The data or research references regarding paddy and rice transportation in Sri Lanka are lacking. Therefore carrying out surveys or research on transportation of paddy and rice in Sri Lanka is useful in future LCA studies.
- The normalization in this work was done using normalization factors relevant only to climate change as data relevant to Sri Lanka for other impacts were not available. Development of normalization factors for Sri Lanka is another possible future work that one could study.
- Eutrophication is a major environmental impact of parboiling process observed in this work. Development of suitable wastewater treatment plants for treating this wastewater is another area that work could be carried out in the future.
- The CO emissions of the biomass combustion in cook stoves and boilers gave higher environmental impact compared to the air emissions of other processing steps. Main reason for this is low values of energy efficiency of current boilers and stoves. Therefore further research works and studies on the improvement of energy efficiency of cook stoves and boilers with reduction in energy losses are needed. One suggestion for this is the study of utilization of waste heat of the boiler to preheat the paddy husk and reduce the moisture content of the paddy husk before combustion.

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