論文の内容の要旨

論文題目　Study on Recycling Systems for Effective Utilization of Palm Oil Waste in Malaysia

（マレーシアにおけるパームオイル残渣有効利用のためのリサイクリングシステムに関する研究）

氏　名　チュ　ユン　リン

1. Introduction

A growing world population has driven rising demands on oil and fats. As a result, oil palm plantations in Southeast Asia, Indonesia, Malaysia and Thailand are expanding year by year. Palm oil is currently the world's largest source of edible oil, providing 43.1 million tonnes or 27 % of the world's total edible oil and fat production, followed by soybean oil. In the case of Malaysia, palm oil plantations span about 44,800 km2. A total of 87.7 million tonnes of fresh fruit bunches are processed in the palm oil mill annually, resulting in the generation of about 38 million tonnes of solid palm oil waste and 59 million tonnes of palm oil mill effluent during the palm oil extraction. By weight, solid palm oil waste consists of 20.5 million tonnes (54 %) of empty fruit bunch (EFB), 11.4 million tonnes (30 %) of shell, and 6.8 million tonnes (18 %) of fiber. Since the 1960s, all palm oil mills have depended on their own biomass for fuel, using mainly the shells and fibers. However, the EFB have not been optimally used, because they are wet, bulky, and voluminous, which are unfavorable properties for transportation and handling; instead, they have been left by the millers to rot at the palm mill and plantation. Palm oil mill effluent (POME) also represents the largest potential for biomass energy utilization in the country, but this resource is readily available and in need of an efficient and effective means of utilization. In this study, we aim to define or implement 'sustainability' in some form for utilizing palm oil waste, especially for

EFB and to determine how Malaysia can develop new downstream sectors with the aim of creating higher value-added economic activities from the EFB that can in turn contribute to the environment, economy, and society.

2. Methodology

This research begins by describing the broad context of national regulations, policies, and programs in promoting the use of this resource. Technology options that utilize EFB as feedstock in the market are reviewed. Case studies of existing technology options operating in Malaysia are examined for their environmental, economic, and social impacts in the existing system. The Life cycle assessment (LCA) method is used to discuss the environmental impacts of these different technologies by the investigation of material input and energy input flow in connection with EFB use. LCA is performed using SimaPro (version 7.0) software, adopting CML 2 Baseline (2000) method, and World, 1990 is selected as the normalization value for analyses. For economic and social impacts, value added and job opportunities created from recycling EFB are evaluated. From the LCA analysis result, we selected a technology to propose for optimal use of EFB in a region. An optimization model is developed in this study. This model is a new analytical tool that integrates cost, energy savings, greenhouse gas considerations, scenario analysis, and a Geographic Information System (GIS) to provide a comprehensive analysis of alternative systems for optimizing EFB for energy production within a region. Finally, policy recommendations are made regarding the continuing development of recycling this resource.

3. Regulations, policies and initiatives, technology options for promoting use of EFB

Environmental regulations for controlling the emission of solid palm oil waste, especially for EFB have not been imposed. Regulations might be able to act as a driver to establish a standard waste management system or proper treatment of the palm oil wastes in the palm oil mills. Existing driving forces from policy and industry initiatives are reviewed. The research concludes that there exists an uneven understanding of utilizing EFB, mainly because of the different initiatives and approaches of sustainability at the international, national and industrial level. International initiatives are promoting EFB used for fuel and fertilizer. National policies tend to promote EFB as energy source and fiber resource for the wood-based industry. Industry initiatives are promoting EFB mulching and composting as fertilizer, which can solve the EFB disposal problem and help in soil conservation. However, the policies are made without considering the competition of utilization of EFB in other industries. The direction of how to utilize the palm oil wastes in the palm oil mills is under the control of the palm oil company's directive. Research and development in technology on how to utilize the palm oil wastes are well established in Malaysia. Allocation of EFB for different usage in sectors of energy, fiber, and fertilizer should be quantitatively analyzed to ensure sustainable development in every sector.

4. Environmental, economic and social impacts of technologies options

Seven technology options are analyzed: bioethanol production, bio-methane recovery, briquette production, combined heat and power (CHP) plants, composting, medium density fiberboard (MDF) production, and pulp and paper production. We have established a life cycle inventory for the LCA model based on data collected from existing plants and interviews of employees in major palm oil companies and stakeholders that are involved with the technologies in Malaysia, as well as a review of selected literatures and Ecoinvent databases. Ten different impact categories are evaluated: abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, human toxicity, fresh water ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation. The functional unit of the study is set at one tonne of EFB. In the environment impact assessment, two analyses are conducted: (a) Without allocation of avoided products, and (b) With allocation of avoided products, and followed by normalization analysis. Sensitivity analyses for land use effects and electricity generation of raw EFB (65 % moisture content) are also conducted. Results show that the technology that has the least emission is composting, followed by briquette production, MDF production, CHP plant, bio-methane recovery, bio-ethanol production, and pulp and paper production. However, when allocation of products and by-products are considered, the most favorable technology is CHP plant, followed by bio-methane recovery, composting, briquette production, ethanol production, MDF production, and pulp and paper production. In the sensitivity analysis, pulp and paper and MDF production are favorable technologies for land use impacts. Electricity generation potential of a tonne of raw EFB from methane recovery and CHP plant are compared. Based on interviews, publications, and reports, we have collected the capital cost, number of workers, processing capacity, and product price in the market for each technology. EFB is expected to produce about 17 million tonnes annually and make a significant contribution to the country's gross national income (GNI) of about RM 60 ~ 780 million (US$ 0.2 ~ 2.5 billion) and job opportunity of 1500 to 12,000 by fully utilizing it. Paper and pulp production and bioethanol production can create the most value from EFB, however, both technologies required high capital cost. Results show that CHP plant has moderate capital cost, and it can generate relatively high revenues with income of US$ 504 million and 6800 job opportunities, compare to MDF production, briquettes, and composting.

5. Development of optimization model for effective use of palm oil waste as energy resources

Because of their favorable environmental impacts, CHP plants are proposed as a viable technology warranting further study. An optimization model is developed to take into account EFB availability, transportation distances, and the scales and locations of the facilities within a region. The goal is to find a system that optimizes the use of EFB by analyzing the cost, net avoided CO2 emission, and net energy savings with the objective of profit maximization. The state of Selangor is selected as a case study. As of 2003, in Selangor, there are a total of 26 palm oil mills with a net capacity of 857,164 tonnes of EFB per year. First, for mulching EFB in Selangor we estimate the annually gain profits (RM 2.69 - 3.99 million (US$0. 84 - 1.24 million)), net energy savings (126 MJ), and net avoided CO_2 emission (75,518 tonnes CO_2 equivalent). We introduce a strategy by considering the installation of a few same-sized CHP plants controlled by a large company in an area where EFB can hopefully be maximally used. Five scenarios utilizing EFB as an energy resource are discussed. The results show that if EFB is used as fuel in CHP plants instead of only for mulching, there are gains in profits, energy, and avoided CO_2 emission of 2~7 times, 3.5~ 6.5 times, and 1~1.8 times, respectively. The scenario analysis results indicate that Case E, which is a combination of small (1.2 MW) and medium (6 MW) sized of CHP plants in Selangor is the best system compared to other cases, performing well in terms of annually gained profit (RM 27.39 million (US$8.73 million)), net energy savings (780 TJ), and net avoided CO_2 emission (128,270 tonnes CO_2 equivalent).

Conclusions

Existing driving forces from regulations, policy and industry initiatives are reviewed, and environmental, economic, and social consequences of development of recycling technologies are quantitatively analyzed by LCA. The LCA analysis and optimization model developed in this study can contribute to developing sustainable downstream processing in the palm oil industry by giving a clear prescription for the policy makers, project developers, and technology suppliers on the development of systems for utilizing EFB, as a fuel for CHP plants. This will allow interested parties to reap the greatest benefits in terms of profits, avoided CO_2 emissions, and energy generation.

Reference

[1] Malaysian Palm Oil Board, http://www.mpob.gov.my.

[2] PRé Consultants. Introduction to LCA with SimaPro 7; November 2010.

[3] CML, 2002, Characterization factors from LCA handbook, CML, Leiden.