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論文内容の要旨

Energy represents the basic background for the economic and social development of a country. A sufficient and sustainable energy supply is one of the decisive keys to economic growth. Therefore, special care should be taken in planning the energy infrastructure because just a single wrong decision would lead to serious consequences for long time periods. Energy planning offers an opportunity to keep the chance of making wrong decisions as low as possible and is thus an important development policy of a country.

Biomass is an important energy source in Vietnam, particularly in the Mekong delta. It is currently treated as non-commercial energy source, being collected and used locally using low efficiency conversion technologies. During the past decades, several studies focused on specific areas of biomass energy were conducted, but the results to date have not been coherently and systematically integrated. The lack of a comprehensive database on current as well as future predictions of biomass sources has resulted in difficulties in identifying promising technologies and opportunities for investments.

In this context, by conducting energy demand survey in residential and industrial sectors as well as obtaining statistic data on agricultural and forestry production, this study aims to:

- (i) To estimate the current and future energy demand in Mekong Delta;
- (ii) To create a comprehensive picture of the biomass situation in Mekong Delta, including theoretical energy potential and biomass flow through its end uses, and to then determine the potential of unused biomass sources;
- (iii) To identify the most available biomass sources and the amount that could be used for energy production;
- (iv) To develop and evaluate biomass utilization scenarios through variation in the scales of the system and conversion technologies; and
- (v) To orient the Vietnamese government and energy policy makers toward more sustainable biomass utilization in Mekong Delta of Vietnam.

Seven (7) chapters of this dissertation were written in order to present and explain the study results, and

afterwards, discuss about the outcomes of the study. The detail results and outcomes are as follows:

Chapter 1 presents some general introduction about the study, whereas Chapter 2 concentrated on reviewing the entire economy in Vietnam, from both economic and energy points of view. It showed that energy demand in Vietnam has been projected to grow significantly mainly due to population growth, urbanization, industrialization and economic development. Being endowed with renewable energy sources, especially biomass, the promotion of renewable is considered as a strategic move for benefits of economy strengthening, energy security enhancement and local environmental protection. However, due to the existence of several barriers, the application of renewable energy is not well developed in Vietnam. Follow time, the technical and financial barriers can be solved by technology innovation. The establishment of renewable databases, as well as the orientation on conversion technology selection becomes the most important manner toward sustainable energy in Vietnam.

Mekong Delta, which was expected to be the largest biomass producer in Vietnam, was selected as the main geographical boundary for the study. Chapter 3 was dedicated to review the current social economic conditions of study area, Mekong Delta, in order to supply the background data for future projection stage.

Chapter 4 focused on estimating the current trend as well as future projection of energy demand in Mekong Delta. Not only biomass sources which can be derived from agricultural residues, wood residues, human and animal wastes, but also fossil-based energy such as kerosene, diesel oil, LPG and electricity are included in the estimation. Total energy demand in Mekong Delta was estimated to reach 148.0PJ in 2007, of which, 82.0% of total demand was consumed by residential sector. The total demand will increase continuously until 2020, and then decrease from 2020 onwards, mainly due to the replacement of biomass by modern energy types, which have higher energy conversion efficiency. Over projection periods, electricity demand, which is influenced by the situation of urbanization, economic development and the improvement of quality of life, is rapidly increased and overwhelmed the other energy sources. However, electricity production was recognized as the highest GHGs producers in Vietnam. Therefore, in parallel with efforts for better economic achievements, it is needed to develop the sustainable solutions for electricity production.

Chapter 5 devotes to the estimation of biomass production and its potential for energy supply using biomass material flow analysis. In this chapter, the most available biomass sources for energy production and its amount in both current and future periods are observed. The chapter firstly pointed out that Mekong Delta has abundant sources of biomass, mainly driven by agricultural production and land-use conditions. The policy toward economic transformation and urbanization will create a reduction trends in both biomass demand and supply. The amount of un-used biomass is therefore expected to increase over projection period. About 80.0% of un-used biomass sources come from rice residues such as rice husk and rice straw. The concept of rice residue as a fuel for power generation might be a solution to reduce the burden of economic growth and urbanization on the energy sector, the dependence on fossil fuel and the negative environmental impacts.

With the conclusion from chapter 5, the chapter 6 concentrated on the development of different biomass utilization scenarios based on a variety of technical options and different amount of feedstock. The economic and environmental benefits of each scenario are evaluated using a set of evaluation indicators. Depending on the type of technology and the scale of biomass conversion systems, the electricity produced from rice residues could be used to satisfy not only demands within the community but also have the excess product to sell to the national grid. With the replacement of grid-based with biomass-based electricity, all alternatives have lower specific usable energy cost and green house gas (GHG) emissions than the case of business as usual, resulting the negative value of GHG marginal abatement cost. Of the considered scenarios, medium-scale systems were better economic and environmental alternatives than small-scale systems. Systems developed based on gasification technology had a lower environmental impact, but a higher cost for usable energy than steam turbine systems.

Chapter 7 summarized the results of material flow analysis as well as scenario evaluation, and then discussed on the implications of the whole research. It firstly pointed out that in order to adapt with the future energy demand in Vietnam, the investment priority should be given to expand the electricity production system. Of the biomass sources, rice residues are the most available and suitable source for power generation. However, the low

electricity tariff as well as the lack of adequate policy and regulations to purchase power from small power producers is limiting the expansion of biomass based power generation system.

It is expected that, this study would be used as orientation for Vietnamese government and energy policy makers when planning the new electricity infrastructure in Mekong Delta region. Besides, depending on the availability of input data, the same methodologies can also be applied to estimate energy demand, examine the biomass potential in other regions and/or at other scales, such as provincial or community levels. From that, the scenarios towards sustainable energy production would be developed and evaluated.

論文審査の結果の要旨

本論文は、ベトナムのメコンデルタ地域を取り上げ、将来にわたる経済成長に伴い当該地域で必要となるエネルギーについて、需給バランスを現地調査と積み上げ型モデルで推定するとともに、当該地域で産出されるバイオマスをベースにしたシステムの提案と評価を環境システム工学の観点で実施したものである。当該地域での世帯、小規模産業のエネルギー消費の実態・推移に関し、訪問調査、アンケート調査、積み上げ型モデルによる物質収支解析、対策シナリオのデザインと評価を主要課題としている。本論文から得られた主要な結果は、以下の通りである。

- (1) ベトナムの社会基盤の維持に必要なエネルギー源、とりわけ化石燃料とバイオマスの現状をまとめ、そこから発生する環境負荷を概算するとともに、メコンデルタ地域の生活・産業基盤を持続的に維持するためには、現地の環境資源を活用した代替システムを軸とした環境・エネルギー政策が必要であることを指摘している。その上で、メコンデルタの地域特性としての経済成長、産業構造、ならびに農林水産物の産出構造を踏まえて、農産物残渣など未利用バイオマスの利用可能量、およびエネルギー需要量を定量的に算定するモデルを構築している。
- (2) 現地調査によって当該地域の生活起源のエネルギー消費が全体の 8 割を超えることを明らかにするとともに、人口、世帯構成、調理用エネルギー消費に占めるバイオマスエネルギーの割合をパラメータとして、3つのケースを設計し、今後のエネルギー需要を推計している。また、当該地域に立地するレンガ製造、アルコール製造等、小規模工場を対象とし、先と同様なケースで当該地域における産業側のエネルギー需要を明らかにしている。
- (3) 当該地域におけるバイオマス生産量、利用の実態を現地での訪問アンケート調査を通じて推定し、初めてメコンデルタ地域において主要なバイオマスフローの全体構造を把握するとともに、未利用の稲藁の活用が重要であることを明らかにしている。さらに、先の3つのケース設定の下で、バイオマスの需給バランスを明らかにし、バイオマスを利用することの環境的メリットを整理している。
- (4) 当該地域において未利用バイオマスを資源に転換する 3 種類のシナリオ（転換施設の小規模分散立地、2 種類の転換技術の拠点立地）を設計するとともに、そのシステムデザイン（原料、収集、転換施設、用途）を行い、それらの組み合わせから 10 種類のオプションについて、費用、温室効果ガスの削減の観点で比較し、各オプションの温室効果ガス発生量、コスト面の優位性を明らかにしている。また、転換施設を小規模分散立地することは必ずしも効果的ではないことも示している。

以上のように、本論文はこれまで未知であった当該地域の実態データに基づくマテリアルフロー解析を通じて、持続可能なエネルギー供給計画に示唆を与えるとともに、アジア地域における途上国の持続可能な発展に資するバイオマス活用方策の環境計画上の含意を示しており、環境・エネルギー工学、とりわけ環境システム工学の発展に大きく寄与している。よって本論文は博士論文として価値あるものと認める。