Energy System Analysis:Modeling as a Tool in the Introduction of Biofuel in Indonesia

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論文内容要旨

Energy management is central to achieving sustainable development goals. Clean, efficient, affordable and reliable energy services are indispensable for global prosperity [1]. Developing countries in particular, need to expand access to clean and reliable energy services if they are to reduce poverty, enhance competitiveness and promote economic growth. The energy sector is accountable for about 60% of total greenhouse gas (GHG) emissions. The current energy systems are inadequate to meet the needs of the world`s poor; a new design of energy systems with reduced GHG emissions, stable supply and increased end-use efficiency, will therefore be critical for meeting wider development objectives.

With a population of 237 million (2007), Indonesia is by the number of inhabitants the fourth in the world. The country faces serious energy problems, with a changed status from net oil exporter to net importer since 2004, with a highly subsidized price of fossil fuel, depleting oil resources and a strong dependency on oil and gas export for the government`s revenues [2]. For these reasons, the government enacted the so-called Mix Energy Policy (2006) to reduce dependency on oil by the use of a mixture of energy sources utilizing local resources, renewable energy and biofuels, beside fossil fuels.

Among several alternative energy options, the first generation technology for biofuels (fermentation and esterification) has the biggest potential in Indonesia as an alternative fuel source, thanks to the favorable climate conditions, and the availability of land and technology. The challenge of doing business in the development of biofuel in Indonesia as well as in other developing countries, is that the market suffers from a lack of information, infrastructure and institutions [3]. With inadequate assessment and a poorly equipped infrastructure (policy, market, science and technology, and public acceptance), any initiative for a large scale introduction of biofuels will be premature; modeling the introduction of biofuel may help to reduce risks of this initiative.

The objective of this thesis is to assess the introduction of biofuel in the transportation sector through an analysis of the energy system as enacted in Indonesia's Mix Energy Policy. The tool for analysis is energy system modeling. The research framework is shown in Fig.1. Due to the complexity of energy systems, this study uses a multifaceted approach: energy, economics and environment are considered. The biofuel crops considered in this study are: sugarcane and cassava to produce bio-ethanol, and palm oil and *Jatropha curcas* to produce biodiesel. This research can be relevant for energy experts, and policy makers especially in developing countries.

The main research questions are:

1. What is the impact of the introduction of biofuels in Indonesia in terms of energy, economics and environment?
2. What is the potential contribution of technology learning to the biofuel production system?
3. What is the implication of the introduction of biofuels for existing energy system in Indonesia?
4. How was the diffusion process of biofuel introduction in Indonesia, who are the stakeholders and what are decisive elements in the innovation system?

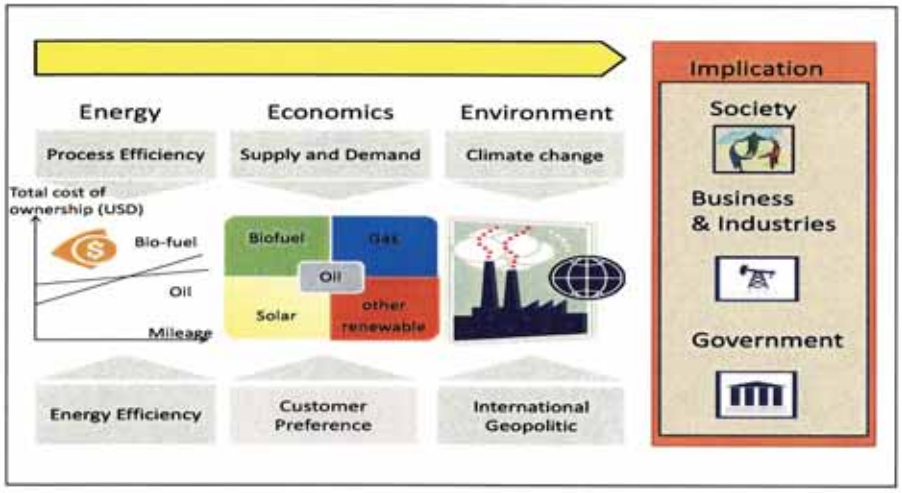

Fig.1. Integrated assessment model of the biofuel introduction in Indonesia

There are 8 chapters that construct this dissertation. Chapter 1 is an introduction. Chapter 2 is a literature review which gives a detailed description of the existing energy and climate policy in Indonesia and the current status of biofuels development in Indonesia. Chapter 3 discusses the methodology for this policy analysis, gives an overview of energy system analysis and of the system innovation in the energy sector [4].

Chapter 4 presents several scenarios regarding the impact of the introduction of biofuels in the transportation sector in Indonesia [5]. This chapter gives to answer the research question 1. A linear programming model is based on land allocation and growth in yield of biofuels crops. The maximum net energy balance is achieved in the 'mix' scenario at 3×10^3 PJ, and the minimum net energy balance is achieved in the 'technology' scenario at 155 PJ. The economic perspectives, at an oil price of 60 US$/barrel, are that

replacement of fossil oil by biofuel in domestic transportation could save 4 billion US$ in 2025. The introduction of biofuel in Indonesia could create around 7×10^6 jobs in 2025, in all but the 'technology' scenario. Under sustainable production, a carbon saving could be achieved of up to 168×10^6 ton CO_2 equivalent in 2025 in the 'mix' scenario.

Chapter 5 elaborates on research question 2 [6]. Technological change such as learning by R&D and economies of scale will have a positive impact on the introduction of biofuel in the transportation sector in Indonesia. The higher net energy balance, higher volume production, as well as decreasing production cost, and higher net emission balances are several benefits that can be derived from technological change. Two important scenarios (with and without technological change) were analyzed by using a multifaceted approach, considering energy, economics and the environment. The maximum net energy balance is achieved at $4x10^3$ PJ in the technology scenario and 900 PJ in the base scenario. The production cost may decrease due to economies of scale. The lowest production cost can be achieved with palm oil production; decrease from 12 US$/GJ in 2007 to 10 US$/GJ in 2025. The net emission balance in 2025 in the base scenario could be 54 Mtce (Million ton CO_2 equivalent) while in the technology scenario it could be 212 Mtce.

Chapter 6 addresses research question 3 [7]. There are two scenario introduced: BAU (with policy) and a `No Policy` scenario which means there is no energy policy to deploy biofuel in transportation sector. The energy supply increases tenfold from 2007 to 2040 to 1,100 Mtoe (Million ton oil equivalent) in the policy scenario. The highest increment in supply comes from coal, followed by gas, fossil oil, hydropower, geothermal power, biomass and biofuel, respectively. Energy demand grows in line with GDP growth of 8% per annum. The CO_2 emissions increase from 250 Mtoe to 3,300 Mtoe in the policy scenario in 2040. In the no-policy scenario the CO_2 emissions jump to 3,400 Mtoe. This shows that the production of biofuel could drop the CO_2 emission by up to about 10^8 ton CO_2.

Chapter 7 looks at research question 4, by using an analytical framework for understanding the process of diffusion of biofuel in Indonesia [8]. Various factors which affect the diffusion and adoption of this new technology are classified into: technology, economics development, sustainability, energy and climate policy, and stakeholders. The stakeholders of the biofuel industries are: producers, users, community, academics, policy makers and international market. There are several barriers for the introduction of biofuel in Indonesia in technology (low yields), economics (competitiveness), sustainability (fuel versus food) and policy (tax and subsidies). These problems can lead to a slow diffusion process and should be overcome. There are several points to consider in this local implementation: lack of technology maturity, the room for participation by the local community, and leadership in the SSEV development. The system also needs to ensure that the project funding is disbursed in an efficient and effective way, with good coordination.

Chapter 8 sums up the research output from chapter 4, 5, 6 and 7 and add some recommendation based on the research result. There are three points to be considered: the limitations of the models, the stakeholders' participation and the dynamics of the market.

Firstly, the limitations of the model are the uncertainty in the predicted outcome, as data were obtained from other countries and foreign biofuel crops. The first recommendation is to improve the model's reliability with original input data from Indonesia`s own biofuel crops. Secondly, the development of biofuel production in Indonesia is still in its infancy. The second recommendation is therefore to assess the potential development with participation of all related parties: the biofuel industries, the workers, local communities and government as policy makers. Thirdly, the transportation sector will change significantly due to technology development, customer preference and policy. It is recommended that the market position of biofuels in Indonesia is continuously monitored in the light of local changes in the transport sector and energy policy, and internationally changes in competing technologies.

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論文審査結果の要旨

インドネシアでは、化石燃料の依存を減らすため、再生可能エネルギーとして良好な気候条件を利用したバイオ燃料が注目されている。インドネシア政府は、2006年にこれら再生可能エネルギーの推進のために、MIX Energy Policyという法律を制定した。本論文は、インドネシアのMIX Energy Policyを考慮して、新たなエネルギーシステム評価モデルを開発し、それを用いた分析を通して、インドネシアの輸送部門へのバイオ燃料の導入効果を評価することを目的としている。

本論文は、その成果をまとめたものであり、全文8章より構成される。

第1章は序論であり、本研究の背景、目的について述べている。

第2章では、インドネシアの既存エネルギー利用の状況とバイオ燃料開発の現状、バイ燃料に関連する気象条件等を、文献により分析している。

第3章では、本研究のエネルギーシステム分析のための方法論について述べている。

第4章では、インドネシアでバイオ燃料を輸送部門に利用する場合の効果を分析できる最適化モデルの開発について述べている。このモデルでは、インドネシアの地域の状況、農業からのリソース、工業化プロセス、需要状況等、を考慮している。輸送分野におけるバイオ燃料の導入は、国内輸送に使われた石油の部分的な代替え、副次製品の輸出による収入、いくつかの部門における雇用の創出、二酸化炭素放出の削減に効果的であることを明らかにした。

第5章は、技術革新に関するモデルの開発とそれを用いた分析結果について述べている。研究開発等に基づく技術革新により、エネルギー利用の効率化、輸出価値の向上、低生産コスト、二酸化炭素放出の削減により、インドネシアの輸送分野へのポジティブなインパクトを与えることを明らかにしている。

第6章は、インドネシアで既存のエネルギーシステムにバイオ燃料を導入する意義を、定量的分析、評価している。インドネシアでのバイオ燃料の導入により、10^8 トンの二酸化炭素削減に寄与することが明らかにしている。

第7章は、バイオ燃料のインドネシアでの普及プロセスについて分析、評価している。普及にはいくつかのバリア、例えば、生産性の低い技術、競争力、持続的確保（食料と燃料と御バランス）、政府の補助金、を克服する必要があることを示している。

第8章では、結論と今後の提案を示している。

本論文は、新たなエネルギーシステム評価モデルを開発し、それを用いた分析を通して、インドネシアの輸送部門へのバイオ燃料の導入効果を明らかにしたものである。今後、インドネシアがバイオ燃料を導入するに当たって指針を示すとともに、技術政策分野の発展に大いに寄与するものである。

よって、本論文は博士(工学)の学位論文として合格と認める。