Renewable Energy Development in Thailand:
A Computable General Equilibrium Model based Analysis

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Abstract

Thailand's economy is susceptible to global energy crises due to its dependence on external energy sources, with about half of its energy supplies coming from overseas. Due to the persistent increase in oil prices since 2004, the Thai government has become more aware of the need to promote the development of domestic renewable energy, particularly biomass fuel. Recently, the National Energy Policy Council (NEPC) approved a 15-year renewable energy development plan (2008-2022) focusing on increasing domestic alternative energy use to replace fossil fuel imports. However, at this stage there is limited knowledge about the economic implications of implementing this plan, including the price effects and impacts on other sectors.

The main objective of this study is to develop a computable general equilibrium (CGE) model for Thailand which features several energy-specific enhancements. The data base utilizes the 2005 Thailand Input-Output (I-O) table. The model is used to simulate a number of potential policies to achieve the bio-liquid fuel targets contained in the 15-year renewable energy development plan. Examples of simulations include abandoning gasoline-95 use, promoting E20 gasohol-95 use, and replacing B2-biodiesel (B2) with unsubsidized B5-biodiesel (B5).

The simulation results indicate that implementing most of the potential bio-liquid fuel promotion policies is unlikely to achieve the set targets. This is because the targets are too high given the current structural constraints. In addition, replacing B2 with B5 needs to be phased to avoid a shortage of biodiesel including palm oil and oil palm. Additional bio-liquid fuel promotion policies such as abandoning gasoline-91 use and promoting B10 use need to be gradually implemented.

Keywords: Computable general equilibrium modeling, energy policy, renewable energy development.

JEL Classification: C68, Q01, Q42, Q43, Q48.

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1. Introduction

Thailand is a developing country in Southeast Asia, with a population of approximately 67 million in 2007 (World Bank, 2009). The average annual real gross domestic product (GDP) growth rate of Thailand was 6.6 percent between 1960 and 2007 (NESDB, 1960-2008). According to Table 1, Thailand's GDP was only US$ 2,760 million at 2000 constant prices in 1960, and per capita GDP was US$ 317. At that time, Thailand's economy was heavily based on the agricultural sector which accounted for 31.5 percent of GDP, while the contribution of the manufacturing sector was only 14.5 percent.

Through a process of continuous transformation from agricultural to more sophisticated manufacturing based economy, as shown in Table 1, Thailand's per capita GDP increased 8.5 times to US$ 2,713 at 2000 constant prices in 2007,[3] while GDP rose about six-fold to US$ 17,315 million. Of this amount, agriculture, the main sector in the past, now plays a lesser role accounting for only 8.6 percent of GDP. On the other hand, the manufacturing sector's share of GDP has grown rapidly to 39.6 percent of GDP.

Table 1: Thailand: Overview of Economy and Energy Use

	1960	**1980**	**2000**	**2007**	**Unit**
GDP (2000 constant prices)	2,760	3,727	12,273	17,315	Million of US$
Per capita GDP (2000 constant prices)	317	796	2,023	2,713	US$
Contribution of agriculture to GDP	31.5	18.6	10.3	8.6	Percent
Contribution of manufacturing to GDP	14.5	24.7	36.4	39.6	Percent
Per capita primary energy use	n/a	487	1,237	1,667	toe
Total final energy use	n/a	15,099	47,806	64,866	ktoe
Final energy use in manufacturing	n/a	3,995	16,208	23,536	ktoe

Sources: World Development Indicators, Various issues; Department of Alternative Energy Development and Efficiency (DEDE), Thailand Energy Situation, Various issues.

The remarkable GDP growth driven by the manufacturing sector has stimulated energy consumption in Thailand. According to Table 1, per capita primary energy use rocketed from 487 tons of oil equivalent (toe) to 1,667 toe between 1980 and 2007. At the same period, final energy use in manufacturing climbed by approximately 6.8 percent per annum from 3,995 kilo tons of oil equivalent (ktoe) to 23,536 ktoe. Correspondingly, Asafu-Adjaye (2000) and Fatai et al. (2004) found that, in the case of Thailand, there exists a two-way causal relationship between economic growth and energy consumption.

[3] Measured using purchasing power parity, the per capita GDP was US$ 8,135 ranked 72nd of the world's economies (World Bank, 2009).

A high level of economic growth leads to a high level of energy demand and vice versa. Thus, energy is an undeniably vital input for economic growth and development in Thailand.

Thailand has heavily relied on fuel imports in which almost half of total energy supply is imported. For instance, in 2007 the value of energy imports was around US$ 2,540 million, approximately 10 percent of GDP, of which 81 percent was in the form of crude oil . As a result, Thailand's economy has been susceptible to fluctuated prices of energy imports. To illustrate this point, Thailand's GDP growth and inflation rate were noticeably escalated by three crises of oil price shocks in the period 1974-1975, 1980-1985, and 2004-2008.

As a consequence, given the high and rising price of oil since 2004, the government has become more aware of the need to promote domestic renewable energy, particularly biomass fuel because it not only helps push some agricultural products' prices upwards, but also reduces energy imports. Recently, the Thailand Energy Ministry has announced a 15-year renewable energy development plan (see Section 2). However, at this stage this plan lacks knowledge about the interactions between the energy sector and other sectors of the economy. There are also no indicators of the price effects of alternative energy development. As a consequent, in order to obtain a detailed impact assessment of the effects of promoting renewable energy, a set of comprehensive and reliable modeling tools for energy policies are essential and urgently required.

Although, there have been a number of computable general equilibrium (CGE) studies which provide economy-wide impact analysis of the Thai economy, to date, none of them have seriously considered energy-sector details and energy policies.[4] Therefore, to fill this important knowledge gap, this study has two main objectives. Firstly, it presents a CGE model for Thailand which features various enhancements to facilitate energy policy analysis. Secondly, the model is used to investigate the impacts of biofuel-promoting measures contained in the Thai government's 15-year renewable energy development

[4] Examples of published CGE studies for Thailand include Amranand and Grais (1983), Phananiramai and Chalamwong (1988), Wattananukit and Bhongmakapat (1989), PARA (1994), Rosensweig and Taylor (1990), Cintakulchai (1997), Siksamat (1998), Charoensedtasin (2000), and Wattanakuljarus and Coxhead (2006).

plan. The results can be used to develop plans to assist Thailand to achieve social and economic sustainable development goals and to improve food and energy security.

The remainder of the paper is organized as follow. The next section provides a brief overview of Thailand's energy situation and renewable energy development plan. Section 3 presents the methodology which focuses on details of the CGE model. The simulation results are presented and discussed in Section 4. The last section summarizes the conclusions and provides policy recommendations.

2. Energy Situation and Renewable Energy Policy in Thailand

According to Table 2, in 2008 Thailand's total primary energy supply was about 112,1957 ktoe of which 62,695 ktoe (55.5 %) was from domestic production, 48,256 ktoe (42.7 %) from net imports and 2,306 ktoe (2.7 %) from inventories. Natural gas was the main source for domestic production which accounted for 24,969 ktoe (39.8 %), while 32.2 percent was from renewable energy sources. Crude oil was the largest form of net import which accounted for 38,128 ktoe (79.0 %), and Thailand still needed to import 8,261 ktoe of natural gas from Myanmar to feed power plants.

As illustrated in Table 2, primary energy was transformed to final energy, causing a net loss of energy of around 42,702 ktoe, approximately 37.8 percent of total primary energy. Therefore, Thailand's total final energy supply in 2008 was 70,255 ktoe. The total final energy consumed was 65,890 ktoe. Of this amount, industry's share was 37.0 percent, transportation's share was 35.0 percent, while the shares of residential, commercial, and agriculture were 15.1, 7.5, and 5.2 percent respectively. About half of the final energy consumed was in the form of petroleum products. The shares of renewable energy, electricity, and coal in final energy consumed were 18.6, 17.5 and 11.8 percent respectively, while natural gas's share was merely 4.8 percent.

In January 2009, the National Energy Policy Council (NEPC) approved a 15-year renewable energy development plan (2008-2022) which is categorized into three stages: short run, medium run, and long run shown in Table 3. The plan focuses on increasing domestic alternative energy use to replace fossil fuel imports. For example, in order to achieve the short run target (i.e., fossil fuel use decreased by 10,960 ktoe accounting for 15.6 percent of total energy use by 2011), electricity from biomass and other renewable sources will be increased by 87 percent from 1,750 megawatts (MW) to 3,273 MW. Also, consumption of heat energy from biomass and other renewable sources will go up by 38 percent to 4,150 ktoe respectively. In addition, biofuel (ethanol and biodiesel) use will be increased by about 200 percent to 2,190 million liters. Lastly, compressed natural gas (CNG) use will increase by approximately 400 percent to 144,540 million standard cubic feet (MMscf).[5]

Table 2: Thai Energy Balance 2008 (in ktoe)

Supply and demand	Coal & its products	Crude oil	Natural gas	Condensate & NLG	Petroleum products	Electricity	Renewable energy	Total
Domestic production	4,743	7,318	24,969	3,900	-	1,577	20,188	**62,695**
Imports	10,026	40,516	8,261	-	884	237	43	**59,967**
Exports	(47)	(2,388)	-	(109)	(9,009)	(101)	(57)	**(11,711)**
Stock changes	225	3,281	-	(446)	(39)	-	25	**3,046**
Total primary energy supply	**14,947**	**48,727**	**33,230**	**3,345**	**(9,204)**	**1,713**	**20,199**	**112,957**
Transformation, own uses, and losses	(7,203)	(48,727)	(30,077)	177	41,254	9,828	(7,954)	**(42,702)**
Total final energy output	**7,744**	**-**	**3,153**	**3,522**	**32,050**	**11,541**	**12,245**	**70,255**
Non - energy uses		-		3,522	843	-	-	**4,365**
Final energy consumption	**7,744**	**-**	**3,153**	**-**	**31,207**	**11,541**	**12,245**	**65,890**

Source: DEDE (1981-2009)

Table 3: Targets for Thailand's 15-year Renewable Energy Development Plan

Forms of Energy	Sources	2008 Existing	2011 Short run	2016 Medium run	2022 Long run	Unit
1. Electricity	**Total**	**1,750**	**3,273**	**4,191**	**5,680**	MW
	Biomass	1,610	2,800	3,220	3,700	MW
	Other	140	473	971	1,980	MW
2. Heat	**Total**	**3,007**	**4,150**	**5,582**	**7,433**	ktoe
	Biomass	2781	3,660	5000	6,760	ktoe
	Other	226	490	582	673	ktoe
3. Bio-liquid fuel	**Total**	**725**	**2,190**	**3,591**	**4,927**	Million liters
	Ethanol	328	1,095	2,263	3,285	Million liters
	Biodiesel	397	1,095	1,328	1,642	Million liters
4. Compressed natural gas		**28,236**	**144,540**	**217,540**	**251,850**	MMscf
Targets: Fossil fuel reduction			**10,960**	**15,580**	**19,800**	ktoe

Source: DEDE (2009)

[5] In Thailand, CNG is commonly called as NGV which stands for Natural gas vehicle. This may confuse non-Thai people when Thai people refer to NGV as fuel instead of a vehicle. Although natural gas is not renewable energy, it is main domestic alternative energy source of Thailand. As a result, the government includes it in the plan.

To reach the target, the government also provides several measures to support this plan which can be summarized as follows: (1) increase the price paid to very small power producers (VSPP) that generate electricity from renewable energy sources; (2) widen the gap of prices between fuel and bio-fuel-mixed fuel by reducing taxes on gasohol and B5;[6] (3) provide financial supports, low-cost loans and incentives to renewable energy projects and technologies; (4) amend laws to support promoting renewable energy.

3. Modeling Approach

Due to advances in computer and computational software, CGE models have been widely employed as tools of policy analysis particularly by both researchers and key international institutions such as the World Bank, International Monetary Fund, and the IMPACT Project (later known as IMPACT/CoPS of Monash University) since the late 1970s. This is because the CGE approach contains several desirable features that allow the economists or policy makers to analyze the impacts of policies and other external shocks on all sectors of the economy.

In contrast, partial equilibrium analysis which is based on only a given market at a time and holding other factors constant is unable to assess impacts on other markets. Although input-output analysis developed by Leontief (1951) considers many markets simultaneously and captures inter-industry linkages, it ignores a role of prices which is an important consideration leading to uniform impacts i.e., all sectors get either better or worse.

As a result, to allow prices play a key role, the first CGE model based on Leontief's Input-Output model was developed by Johansen (1960). However, the demand functions in Johansen's model were not exactly derived from optimization or general equilibrium theory (initiated by a French economist, Leon Walras, and then proved by Arrow and Debreu (1954)). Subsequently, CGE models have been reinforced with general equilibrium theory.

Although macro-econometric modeling is also widely used in economic analysis and prediction, it can not capture impacts of microeconomic shocks and policies on the

[6] Gasohol is a mixture of ethanol and gasoline. For example, E10 gasohol refers to 10 percent of ethanol and 90 percent of gasoline. B5 is a mixture of 5 percent of biodiesel and 95 percent of diesel. In 2008 bio-liquid fuels used in Thailand are E10 gasohol-91, E10 gasohol-95, E-20 gasohol-95, B2, and B5.

economy as other CGE models.[7] In addition, a CGE model requires only one-year's benchmark data instead of extensive time-series data used in macro econometric models. Such data are often unavailable in developing countries such as Thailand.

3.1 Model

The model employed in this study is a modified version of the well-known Australian ORANI model (Dixon et al., 1982). Like ORANI, this model is a comparative-static, multisectoral, multiproduction, single country model. It is based on the Johansen approach in which a system of nonlinear equations is transformed to that of linear equations and then can be simply solved by matrix manipulation.[8]

Like standard CGE models, this model is based on neo-classical assumptions about agents' behavior, production, and consumption structures. The economic agents in the model consist of producers, one household, investors, the government, and an external sector (foreign demand). Demands for commodities by producers, the household, investors, and the government are derived from cost (or profit) or utility optimization problems. All producers (industries) maximize profits (or minimize cost) conditional on competitive markets and constant returns to scale production technologies. In the case of multi-product industries, they are assumed to produce a constant elasticity of transformation (CET) composite of products.[9] The household maximizes utility subject to its budget constraint, while investors and the government minimize cost subject to specific constraints. By contrast, foreign demands for commodities are given as specific behavioral functions.

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[7] Also, Devarajan and Robinson (2002)gave an example that during the first and second oil crises of the 1970s, macro-econometric models failed to capture the impact of large changes in world oil prices because they were based on past data in which oil prices were relatively stable.

[8] Another approach of CGE models is the Haberger-Scarf-Shoven-Whalley tradition (Herberger, 1962; Scarf, 1967; Shoven and Whalley, 1992). This approach solves non-linear general equilibrium problems in levels rather than in log differential form. One of the drawbacks of this method is that the size of model can become a problem and another difficulty is that it needs to be redeveloped after any changes in model specification (Asafu-Adjaye, 1996), while the main advantage Johansen style is its flexibility in terms of model size, model modification and model application (Dixon et al., 1982).

[9] CET technology allows producers to adjust amounts of various products according to changes in relative prices of the products to reach maximized profits.

In order to conform to the economic structure and Thailand's 15-year renewable energy development plan, our model features seven main enhancements which are discussed below.

3.1.1 Energy Sector

The model contains 51 industries and 62 commodities, as listed in Table 4. We disaggregated the energy-source sector into 24 energy industries (Industry 1 to 24) and 32 energy-source commodities (Commodity 1 to 34 including Paper Production Residues except Other Crops Milled Rice, and Sugar). In order to assess the impacts of promoting bio-liquid fuels, we created Molasses-Ethanol, Cassava-Ethanol and Biodiesel industries along with disaggregating four mixed-bio-liquid fuel industries (Gasohol-91, Gasohol-95, B2, and B5) treated as dummy industries of the petroleum refinery industry. The disaggregation facilitates imposing policy shocks such as increase in capital stocks in the Molasses-Ethanol, Cassava-Ethanol and Biodiesel industries in the short run. In addition, the model can simulate various scenarios such as adding more bio-liquid fuels to mixed-bio-liquid fuels, for example, increasing the biodiesel content in B2 from 2 percent to 5 percent (B2 to B5).

Furthermore, in order to measure the effects of subsidizing biomass-fired power plants, according to different technologies, the electricity sector was disaggregated into four new industries: Main Electricity, Hydro Power, SPP and VSPP. Main Electricity is a group of main power producers and distributors such as the Electricity Generating Authority of Thailand (EGAT) and its subsidiary companies. This industry generates electricity from fossil fuel accounting for about 92 percent of total generation. The Hydro Power sector contributes approximately 5 percent to total generation, while about 3 percent is generated from mostly biomass by small power producers (SPP) and very small power producers (VSPP).[10] This disaggregation allows us to analyze energy policies and energy shocks more precisely and extensively than previous CGE models.

[10] SPP which generates electricity from fossil fuels is included in Main Electricity. In this study, SPP and VSPP are referred to biomass-based power producers.

Table 4: List of Industries and Commodities

	Industry	I-O code		Commodity
1	Cassava	004	1	Cassava
2	Sugarcane	009	2	Sugarcane
3	Oil Palm	011	3	Oil Palm
4	Other crops	001-003, 005-008, 010, 012-017, 24	4	Other Crops
			5	Agricultural Residue
5	Charcoal and Firewood	026	6	Charcoal
			7	Firewood
6	Rice Milling	049	8	Milled Rice
			9	Paddy Husk
7	Sugar Refineries	055	10	Sugar
			11	Molasses (including sugar cane juice)
			12	Bagasse
8	Petroleum and Natural Gas	031	13	Crude Oil
			14	Raw Natural Gas
			15	Condensate
9	Natural Gas Processing	136	16	Natural Gasoline and Others
			17	Processed Natural Gas
			18	Liquefied Petroleum Gas (LPG)
10	Petroleum Refinery	093-94	19	Gasoline-91 (Regular gasoline)
			20	Gasoline-95 (Premium gasoline)
			21	Diesel
			22	Jet Fuel
			23	Fuel Oil
			24	Other Petroleum Products
11	Gasohol-91	93	25	Gasohol-91 (E10)
12	Gasohol-95	93	26	Gasohol-95 (E10)
13	B2	93	27	Mixed Biodiesel (B2)
14	B5	93	28	Mixed Biodiesel (B5)
15	Main Electricity	135	29	Electricity
16	Hydro Power			
17	SPPP (Biomass and Mixed Fuel)			
18	VSPP (Biomass)			
19	Coal	030	30	Coal
20	Palm Oil	047	31	Palm Oil (including crude palm oil)
21	Tapioca Milling	50	32	Tapioca Products (including cassava chip)
22	Biodiesel	-	33	Biodiesel (B100)
23	Molasses-Ethanol	-	34	Ethanol
24	Cassava-Ethanol			
25	Livestock	018-023	35	Livestock
26	Forestry	025, 027	36	Forestry
27	Fishery	028-029	37	Fishery
28	Mining and Quarrying	032-041	38	Mining and Quarrying
29	Food Manufacturing	042-046, 48, 051-054, 056-061	39	Food Manufacturing
30	Beverages and Tobacco	062-066	40	Beverages and Tobacco
31	Textile Industry	067-074	41	Textile Industry
32	Wood and Furniture	078-080	42	Wood and Furniture Products

Table 4: List of Industries and Commodities (Cont'd)

	Industry	I-O code		Commodity
33	Paper Products and Printing	081-083	43	Paper Products and Printing
			44	Paper production residues (energy)
34	Chemical and Rubber Products	084-092, 095-098	45	Chemical and Rubber Products
35	Non-Metallic Products	099-104	46	Non-Metallic Products
36	Basic Metal	105-107	47	Basic Metal
37	Fabricated Metal Products	108-111	48	Fabricated Metal Products
38	Machinery	112-128	49	Machinery
39	Other Manufacturing	75-80, 129-134, 137	50	Other Manufacturing
40	Construction	138-144	51	Construction
41	Wholesale Trade	145	52	Wholesale Trade
42	Retail Trade	146	53	Retail Trade
43	Rail Transportation	149	54	Rail Transportation
44	Road Transportation	150-152	55	Road Transportation
45	Water Transportation	153-155	56	Water Transportation
46	Air Transportation	156	57	Air Transportation
47	Public Services	165-169	58	Public Services
48	Other Services	147-148, 157-164, 170-179	59	Other Services
49	Unclassified	180	60	Unclassified
D1	Private Transportation	Dummy Sector	D1	Private Transportation
D2	Government Transportation	Dummy Sector	D2	Government Transportation

3.1.2 Structure of production

We assume complementarity between non-energy intermediate inputs and a factor-energy composite. Therefore, at the top level of the nests as shown in Figure 2, they are aggregated in fixed proportions (Leontief technology). However, in cassava-based ethanol production, cassava and tapioca chips are considered as substitutes, thus they are combined using a constant elasticity of substitution (CES) functional form. [11]

At the lower levels of the nest, the factor-energy composite is a CES bundle of capital-energy composite, labor, and land. Labor is a CES composite of unskilled and skilled labor. The capital-energy composite is aggregated by capital and the energy composite via a CES function. The energy composite is obtained by combining all energy inputs (see Figure 3). Each intermediate input is a CES composite of domestic and imported inputs known as the Armington approach.

[11] The CES technology is here employed to allow substitutability between inputs. Also, in the case where inputs are complements, it can be switch to Leontief technology by setting the elasticity of substitution to zero. To be consistent, in this study using CES functions means that things are substitutes.

Figure 2: Structure of Production

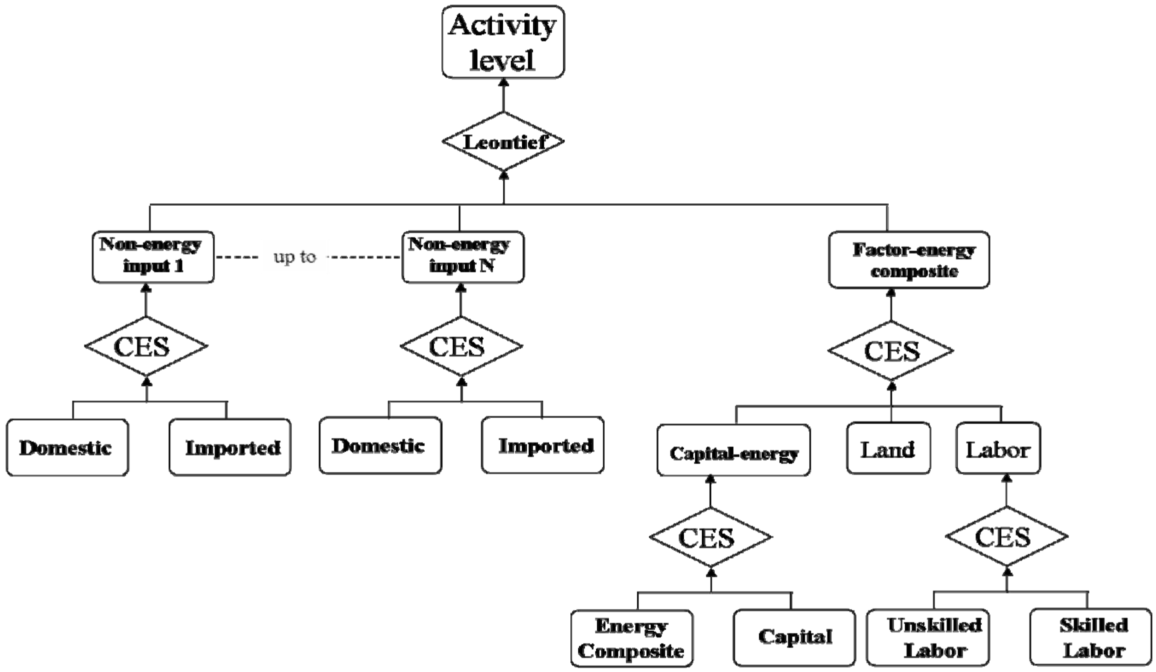
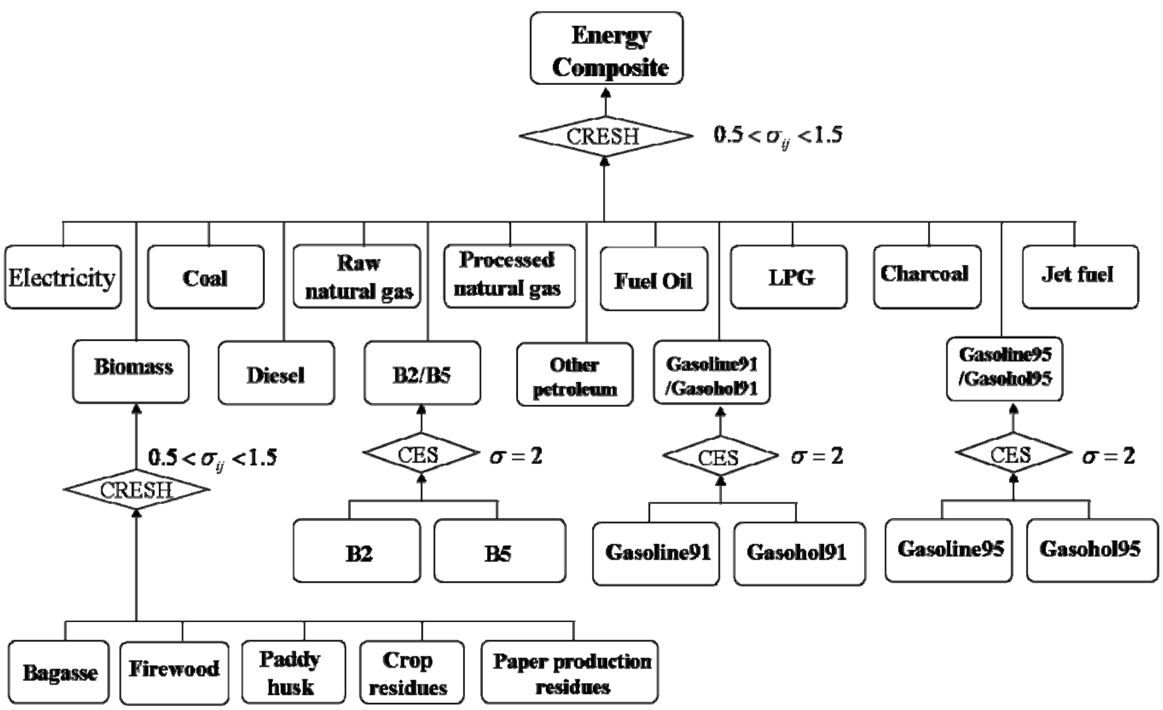


Figure 3: Structure of Energy Composite



Electricity, coal, raw natural gas, processed natural gas, fuel oil, LPG, charcoal, jet fuel, biomass composite, diesel, other petroleum products, gasoline91-gasohol91 composite, and gasoline91-gasohol91 composite are combined using CRESH technology. The biomass composite is a CRESH composite of bagasse, firewood, paddy husk, agricultural residue, and black liquor, while the B2-B5, gasoline-91-gasohol-91, and gasoline-95-gasohol-95 composites are CES composites.

It is important to note that some energy sources such as crude oil, condensate, natural gasoline (NGL), ethanol, biodiesel are used as feedstock or for non-fuel purposes. As a result, they are not in the energy composite, but they are rather treated as intermediate inputs. Furthermore, several energy sources are used both for fuel and non-fuel purposes. An example is LPG which is used as fuel in most industries and households whereas they are used as feedstock in the petrochemical sector. To make sure that the energy composite used in each sector is all used as fuel, we utilize a matrix of energy usage shares. As a result, energy commodities used as fuel go into the energy composite, while the ones used as non-fuel are treated as intermediate inputs.

3.1.3 Energy-capital substitutability/complementarity

The issue of whether capital and energy are substitutes or complements remains unresolved given a number of contradictory empirical studies (e.g. see Burniaux and Truong, 2002, Table 8). This inconsistency is likely to result from the difference between flexibility in energy-capital usage in the long run and inflexibility in the short to medium term (Burniaux and Truong, 2002). To account for this, we followed Borges and Goulder (1984) by considering the elasticity of substitution between capital and energy in the capital-energy nest (σ_{KE}) and the overall, output constant, elasticity of substitution between capital and energy in the energy-primary factor nest ($\sigma_{KE-overall}$), using the following formula proved by Keller (1980) for the case of a nested CES:

$$\sigma_{KE-overall} = \left[\sigma_{KE} - \sigma_{EF}\right] / S_{KE} + \sigma_{EF} / S_{EF} \qquad (1)$$

where S_{KE} and S_{EF} are the cost share of the capital-energy bundle and the cost share of the energy-primary factor bundle respectively, and where σ_{EF} is the elasticity of substitution between energy and primary factors which has a positive sign. That is, capital-energy, labor, and land are substitutes.

The OECD's GREEN model (Burniaux et al., 1992) and the GTAP-E model (Burniaux and Truong, 2002) also considered the framework of Borges and Goulder (1984). They set values of σ_{KE} and let values of $\sigma_{KE-overall}$ to vary. This setting may cause $\sigma_{KE-overall}$ to be less than zero, which implies capital-energy complementarity but not capital-energy rigidity in the short term. In contrast, to imply capital-energy rigidity in the short term, we set $\sigma_{KE-overall}$ equal to zero. Therefore,

$$\sigma_{KE} = \sigma_{EF}\left(1 - S_{KE}/S_{EF}\right) \tag{2}$$

and due to $S_{EF} > S_{KE}$ and $\sigma_{EF} > 0$, σ_{KE} is greater than zero implying capital-energy substitutability in the long term. In addition, this structure in turn implies that energy can be substituted by labor and land and vice versa, i.e. energy-factor substitution. Given the elasticity of substitution between factors of 0.5, the elasticity of substitution between capital and energy in each industry varies from 0 to 0.5, implying that they are low substitutes.

3.1.4 The Oil Fund and Fuel Excise Tax

The Oil Fund was established to stabilize domestic retail petrol prices by subsidizing domestic oil producers and importers when the ex-refined prices are high and taxing them when they are low. In addition, its role seems to distort fuel markets since it imposes taxes on mainly gasoline and diesel, while subsidizing a number of fuel prices such as LPG, gasohol, mixed-biodiesel, and diesel for coastal fishing.

In addition, the excise tax on petroleum fuels is one of the main incomes of the government, for example, accounting for 6.8 and 3.5 percent of total government net revenue in 2005 and 2008, respectively (Ministry of Finance, 2009). The reason why the figure dropped dramatically is because the government cut fuel excise tax rates to provide relief for the high oil price in 2008. Furthermore, the government can either narrow or widen the price margins between, for instance, petroleum fuels and bio-liquid-fuels by changing fuel excise tax rates in order to achieve targets for its energy policies. This implies that determination of fuel excise tax rates plays a key role in energy prices and Thailand's economy.

As a result, it is necessary to consider the fuel excise tax and Oil Fund tax in the model. However, due to the time constraint we combined the Oil Fund and fuel excise taxes into one rate which we call the fuel tax rate which is treated as sales tax (margin), whereas other indirect taxes are considered as output tax. This allows us to shock the fuel tax rate variables for different users. For example, if the government wants to achieve the target of the Renewable Energy Plan, it may impose more levies on LPG used in transportation in order to force LPG users to use less LPG and switch to appropriate alternative fuels such as CNG and gasohol.

3.1.5 Introduction of technological shifters for measuring impacts of fuel replacement

We introduce a set of technological shock variables which are used to measure the impacts of legally-enforced fuel replacement, for instance, the replacement of gasoline-95 with gasohol-95, gasoline-91 with gasohol-91, or B2 with B5. To illustrate this point, let us consider the octane 95 gasoline composite. Without the technological shifters, the demand function for gasohol-95 can be written in percentage change form as follows:

$$x_{gsh95} = \bar{x}_{95} - \sigma_{95}\left(p_{gsh95} - \bar{p}_{95}\right) \tag{3}$$

where x_{gsh95} and p_{gsh95} are quantity demanded and price of gasohol-95 respectively; $\bar{x}_{95}$ and $\bar{p}_{95}$ are quantity demanded and price of the gasoline-gasohol composite respectively; and σ_{95} is the elasticity of substitution between gasoline-95 and gasohol-95.

When the technological shifters are introduced, the demand function for gasohol-95 and the gasohol-95 technological shifter (a_{gsh95}) equation can be respectively rewritten as:

$$x_{gsh95} = \bar{x}_{95} - \sigma_{95}\left(p_{gsh95} - \bar{p}_{95}\right) + a_{gsh95} \tag{4}$$

and

$$a_{gsh95} = -\frac{S_{gsl}}{S_{gsh95}}.a_{gsl} \tag{5}$$

where S_{gsh95} and S_{gsl} are gasohol-95's share and gasoline-95's share of the gasoline-95-gasohol-95 composite respectively, while a_{gsl} is the gasoline-95 technological shifter. In this case a_{gsl} is the exogenous variable, while a_{gsh95} is endogenous. For example, let us assume that S_{gsh95} and S_{gsl} are 0.2 and 0.8 respectively, and the government wants to abandon gasoline-95 use, implying that gasoline-95 use drops by 100 percent, i.e. a_{gsl} = - 100. This leads to a_{gsh95}= 400 which means that, *ceteris paribus*, the demand for gasohol-95 will increase by 400 percent due to abandoning gasoline-95.

Furthermore, bio-liquid fuel use is being promoted by, for instance, increasing biodiesel content in B2 from 2 to 5 percent (B2 to B5) and increasing ethanol content in gasohol-95 from 10 to 20 percent (E10 to E20) (Ministry of Energy, 2009). In the future, fuel users will be forced to use B10 instead of B5 and also E20 gasohol-91 instead of E10 gasohol-91. Consequently, we have also designed the model for these possible scenarios.

To illustrate this point, let us consider the E10 gasohol-95 production. Production of 100 liters of gasohol-95 (E10) requires 90 liters of octane 91 gasoline and 10 liters of ethanol. Again, when the technological shifters are introduced, the demand function for gasoline-91 and the gasoline-91 technological shifter (a_{gsl91}) equation can be written as follows:

$$x_{gsl91} = \bar{x} - \sigma\left(p_{gsl91} - \bar{p}\right) + a_{gsl91}, \text{ and } a_{gsl91} = -\frac{10}{90} a_{ethanol} \tag{6}$$

where the number 10 refers to the ethanol content in E10 gasohol-95, while the number 90 refers to the gasoline-91 content,[12] while $a_{ethanol}$ and a_{gsl91} are ethanol and gasoline-91 technological shifters, respectively.[13] To illustrate this point, when the industry is forced to produce E20 instead, that means, *ceteris paribus*, the demand for ethanol increases by 100 percent (or $a_{ethanol}$ = 100). This results in a_{gsl91} = – 11.11, which

[12] x_{gsl91} and p_{gsl91} are quantity demanded and price of gasoline-91 respectively, $\bar{x}_{gsh}$ and $\bar{p}_{gsh}$ are quantity demanded and price of the 91 gasoline-ethanol composite (gasohol-91) respectively, and σ_{gsh} is the elasticity of substitution between gasoline-91 and ethanol.

[13] How ever this study set both of them as exogenous due to a huge magnitude of shocking and dropped the technical shifting equation instead.

means that the demand for gasoline-91 drops by 11.11 percent. Similarly, demands for gasoline-91 and ethanol in the gasohol-91 can be considered in the same way.[14]

3.1.6 Private transportation and transportation used by government sector

Household (private) transportation is one of the largest energy users and can be substituted particularly by public transportation. In order to measure the effects of policy shocks on households' mode of transport, we have created a dummy industry, private road transportation, whose intermediate inputs are vehicles, fuel, lubricant, repairs, parts, etc. (e.g. see Adams et al., 2003; Lee, 2002). The model in turn incorporates substitution between private transportation and other modes of public transportation. In addition, we created a dummy industry of government transportation to not only facilitate the structure of government demand but also allow substitution between the modes of transportation.

In addition, we categorized commodities consumed by households and government into three bundles: energy, transportation, and other goods. Energy and transportation bundles are CRESH composites, while the other goods bundle is a CES composite. Then in the case of household demand, the three bundles are combined via a Stone-Geary (or Klein-Rubin), while in the case of government demand they are combined via a Leontief (fixed proportions) function.

3.1.7 Land mobilization

Land mobilization is particularly important in the agricultural sector. For example, if the relative price of cassava to rice increases, land use in the rice sector will be allocated to more use in cassava production. The issue of land use mobilization between sectors was ignored in the original ORANI model, which we address in this model. We assume that in the long run cultivated land use in all agricultural sectors can be efficiently allocated according to the market mechanism, while in the short run land can only be mobilized between three similar crop industries: cassava, sugarcane, and other crops (mainly rice).

[14] In the case of increasing biodiesel content in B2 from 2 to 5 percent (B2 to B5) the demand and technical shifting equations can be written as $x_{diesel} = \bar{x}_{B5} - \sigma_{B5}\left(p_{diesel} - \bar{p}_{B5}\right) + a_{diesel}$, and $a_{diesel} = -\frac{2}{98}a_{B100}$, while $x_{diesel} = \bar{x}_{B10} - \sigma_{B10}\left(p_{diesel} - \bar{p}_{B10}\right) + a_{diesel}$, and $a_{diesel} = -\frac{5}{95}a_{B100}$ are for the B10 production (B5 to B10).

Note that we do not allow land use in oil palm production to be mobilized in the short run since oil palm takes about five years to be yield a commercial harvest, while sugarcane cassava, and rice take less than one year.

In the short run model scenario, land use in oil palm is assumed to be fixed. On the other hand, we allow the land rentals (prices) of the three crop industries to move along with the average price of their products. Then demand for land in each of the three sectors will be determined by the ratios of the land rental paid to product price received. Similarly, in the long run scenario, we allow land rentals of the four agricultural sectors (instead of only three industries) to be determined by the average price of their products.

3.2 Model Closure and Solution

The model system can be represented in a general form as:

$$Az = 0 \tag{7}$$

where A is a matrix of coefficient and z is a vector of variables in percentage change form. The model contains *156,015* equations and *293,451* variables. That means the system requires *137,436* exogenous variables to facilitate a solution. One of the exogenous variables must be a price variable, a numeraire, which is used to express other prices as relative prices to the numeraire. In this study we choose the exchange rate as the numeraire.[15]

The exogenous variables include technological changes, taste changes, indirect tax rates, tariff rates, shift variables, and fixed factors. On the other hand, the other exogenous variables in the short-run closure must be swapped with the endogenous ones in the long-run closure, while the other exogenous variables in the long-run closure must be swapped with the endogenous ones in the short-run closure. These variables are shown in Table 5.

After the model closure is done, the model can be rewritten as:

$$A_1 y + A_2 x = 0 \tag{8}$$

where y and x are denoted as, respectively, the column vectors of endogenous and exogenous variables, and A_1 and A_2 are the coefficient matrices corresponding to the vectors of endogenous and exogenous variables (y and x), respectively. Therefore, when

[15] Normally, either the exchange rate or consumer price index (CPI) is selected to be the numeraire.

one or more of the exogenous variables (x) are given, we can solve the above system for endogenous variables (y) using matrix operations as: [16]

$$y = A_1^{-1}(-A_2 x) \tag{9}$$

Table 5: List of Exogenous Variables

Exogenous variables for short-run closure	Exogenous variables for long-run closure	Size
Capital used by each industry (Excluding SPP and VSPP)	Sectoral gross rates of return (Excluding SPP and VSPP)	IND - 2
Average real wage	Total employment - wage weights	1
Real private consumption expenditure	Balance of trade to GDP	1
Real investment expenditure	Shift variable linked to Real private consumption expenditure	1
Real government expenditure on goods	Shift variable linked to Real private consumption expenditure	1
Land use in oil palm production	Industry-specific land rental shifter	1
Natural exogenous Variables		
Capital stocks in SPP and VSPP industries [17]		2
Fixed factors (excluding land use in the four crop industries)		IND-4
Real demands for inventories		IND*SRC
C.I.F. foreign currency import prices		COM
Number of households		1
Abandoning shifters of gasoline-95		IND
Abandoning shifters of gasoline-91		IND
Abandoning shifters of subsidized B5		IND
Technical content shifters		6
Others including technical change, taste change, and tax rate variables[18]		137,009

Note: IND is the number of industries in the model which is 51; COM is the number of commodities which is 62; and SRC refers to two sources: domestic and imported.

3.3 Database and Model Parameters

The model's main data sources comprise Input-Output data and a set of elasticity parameters. The 2008 Input-Output data for this research were created utilizing the 2005 national Input-Output table produced by NESDB (see Appendix 1).[19] Note that since the original I-O table does not provide the use of agricultural land, we utilized the land income share (0.0289) to estimate total land rental payment from total factor payment.[20] Then we distributed the figure to the agricultural sectors according to their capital

[16] The model was solved using Version 9 of GEMPACK (Harrison and Pearson, 1996)
[17] Their production capacity is determined by the government policy.
[18] The Main Electricity industry's production tax rate is endogenized to response to subsidizing electricity generated from biomass.
[19] Various additional sources of survey data published by economic organizations were required such as NESDB, the National Statistics Office (NSO), the Office of Agricultural Economics (OAE), the Excise Department, DEDE, and Energy Policy and Planning (EPPO).
[20] The figure was obtained from the Bank of Thailand (2000).

payments. Furthermore, natural resource payments in some industries such as Forestry, Fishery, Petroleum and Natural Gas, Coal, and Mining are obtained by using proportional figures from the GTAP 6 data base (Dimaranan, 2006). However, we treated these payments including half of the capital payment in Hydro Power as land rentals. Eventually, we yield the 49-industry, 60-commodity, 2-labor, 6-margin Input-Output table including 2 dummy industries and commodities (private and government transportation sectors), which is consistent with the model's energy specification.[21]

Most of the elasticity parameters used in the model were obtained from other studies mainly from the GTAP 6 data base, while some were guesstimated based on our knowledge and experience. For example, to obtain CRESH elasticity parameters of substitution between fuels used each sector, we assumed the values vary from 0.5 – 1.5 weighted by their energy use share and we used the formula, $\sigma_{ij} = 1.5 - S_{ij}$, where σ_{ij} is the CRESH elasticity parameters of substitution of energy *i* in sector *j*, while S_{ij} is the energy use share of energy *i* in sector *j*.[22] The larger the energy use share, the less substitutable it is. In addition, since gasohol and gasoline are high substitutes including B2 and B5, the CES elasticity parameters of these composites are set at 2.0. The key elasticity parameters are shown in Appendix 2.[23] According to Tanboon's study (2008), the Frisch parameter is set at -3.03. In addition, the economy-wide level of gross to net rate of return ratio is set at 1.358, calculated from the ratio of total capital rental to total capital rental less depreciation.

3.4 Simulation Scenarios

This study assesses the feasibility and impacts of the targets for Thailand's 15-year renewable energy development plan. However, the policies relating to electricity generated from biomass, NGV and LPG were omitted from this study due to time and space limitations. Therefore, we focused on only strategies related to bio-liquid fuel policies. According to Table 3, to achieve the targets, ethanol use must increase by 234

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[21] Margins are categorized into six items: retail trade, wholesale, road, rail, water, and air transportations.
[22] For instance, CES elasticity parameters of substitution between fuels vary from 0.5 to 1 in GTAP-E and 0.25 to 2 in the OECD's model.
[23] Since the behavioral parameters employed in this study are not obtained from econometrical estimation, the study results must be interpreted with caution.

percent from 328 million liters in 2008 to 1,095 million liters by 2011 and biodiesel use must increase by 176 percent from 397 million liters in 2008 to 1,095 million liters by 2011. The likely bio-liquid fuel promoting strategies to achieve the targets are shown in Table 6. It is important to note that ethanol promoting strategies can be sequentially combined and implemented, while one of biodiesel promoting strategies is chosen.

Table 6: List of Provisional Strategies Expected to be Implemented by the Thai Government

Ethanol promoting strategies	Biodiesel promoting strategies
1. Abandoning gasoline-95 use	1. Replacing B2 with B3
2. Promoting E20 gassohol-95 use	2. Replacing B2 with B4
3. Abandoning gasoline-91 use	3. Replacing B2 with unsubsidized B5

Therefore, short-run simulations and long-run simulations were conducted to estimate the impacts of the following bio-liquid fuel promoting measures:

- Policy A: a 100 percent decline in gasoline-95 use in all sectors except the petroleum refinery industries;
- Policy B: a 50 percent increase in ethanol content in gasohol-95 (approximately E10 to E15) combining with Policy A;[24] and
- Policy C: a 100 percent decrease in B5 use in all sectors and a 150 percent increase in biodiesel content in B2 (B2 to B5), and;[25]

Note that since 2008 the government has continuously allowed additional ethanol and biodiesel producers to enter to the biofuel market. As of February 2010 there were 17 operational ethanol factories producing 2.75 million liters/day compared to 10 factories producing 1.55 million liters/day in December 2008 (sources: (DEDE, 2010a)).[26] As a result, for the short-run closure of the Policies A and B, the capital stock of the cassava-based ethanol industry was increased by 500 percent, while that of the molasses-based

[24] We assumed that the government is likely to promote E20 gasohol-95 use at least equal to E10 gasohol-95 use before abandoning E10 gasohol-95 use in the next stage. However, the model is unable to differentiate these commodities so we treat them as E15 gassohol-95 (50 percent of E10 and 50 percent of E20). That is why the ethanol content in E10 gassohol-95 is assumed to increase 50 percent.

[25] This simulation means that the output produced by the B5 industry is abandoned and in turn the B2 industry becomes the B5 producer instead.

[26] From December 2008 to February 2010 (1.2 years) the molasses-base ethanol production capacity increased from 1.42 to 1.97 million liters/day, while the cassava-base ethanol production capacity rose from 0.13 to 0.78 million liters/day. Since short-run period is about 2 years, the figure 1.2 years is roughly referred to the first half of the short run period which is spent to install new capital; and it in turn is utilized in the second half.

ethanol industry was increased by 38.7 percent. In the case of Policy C, the capital stock of the biodiesel industry was increased by 48.7 percent due to increase in the capacity of biodiesel production from 4.1 to 6.1 million liters/day in the same period (DEDE, 2010b).

4. Simulation Results and Discussion

This section of presents and discusses the results for the short- and long-run impacts of the three selected liquid bio-fuel promotion policies. Only three policies were selected for analysis due to space constraints. They were chosen because they are the most likely to be implemented. Also, due to space limitations, only the key results are presented. These are the macroeconomic impacts, impacts on sectoral output and the price impacts.

4.1 Effects of Policy A: 100 Percent Reduction in Gasoline-95 Use in all Sectors except Petroleum Refining

4.1.1 Macroeconomic impacts

Given the increase in the ethanol industries' capital stocks, abandoning gasoline-95 use has a small negative impact in the short-run. Real GDP contracts by 0.02 percent due to the worsening balance of trade. Real imports grow by 0.15 percent, while real export grows at a slower pace of 0.12 percent, resulting in a small decline in terms of trade (Table 7, column A). Due to real wages being held constant, aggregate employment declines by 0.05 percent, while the CPI increases by 0.15 percent. Furthermore, the revenue from fuel taxes slightly declines by 1,390 million baht.

Our results indicate that in the long-run, the negative trends observed above are reversed. Real GDP grows 0.04 percent due to the fact that aggregate investment rises by 0.09 percent, and real exports grow by 0.27 percent, even though real household and government consumption fall by 0.05 percent. The CPI increases by 0.11 percent. With aggregate employment held constant, the average real wage declines by 0.05 percent. In addition, the terms of trade decline by 0.07 percent and the revenue from fuel taxes declines by 1,332 million baht.

Table 7 Results for the Short- and Long-Run Impacts of Promoting Bio-liquid Fuel Policies

Impacts	Policy A		Policy B		Policy C	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Macroeconomic impacts:						
Real GDP	-0.02	0.04	0.00	0.03	-0.08	0.02
Real household consumption	0.00	-0.05	0.00	-0.02	0.00	0.08
Consumer price index (CPI)	0.15	0.11	0.08	0.07	0.37	0.10
Real government expenditure	0.00	-0.05	0.00	-0.02	0.00	0.08
Aggregate investment	0.00	0.09	0.00	0.03	0.00	-0.02
Import volume index	0.15	0.21	0.08	0.10	-0.16	-0.15
Export volume index	0.12	0.27	0.08	0.14	-0.25	-0.18
Terms of trade (TOT)	-0.04	-0.07	-0.02	-0.04	0.06	0.04
Aggregate employment	-0.05	0.00	-0.01	0.00	-0.10	0.00
Real wage	0.00	-0.05	0.00	0.00	0.00	-0.01
Change in net fuel taxes	-1,390	-1,332	-1,681	-1,604	9,936	6,986
Sectoral output:						
Cassava	2.58	1.20	3.77	6.27	-0.21	-0.21
Sugar cane	0.05	0.10	0.12	0.00	-0.10	-0.11
Oil palm	0.00	0.16	0.00	0.06	3.61	14.64
Other crops	-0.05	-0.04	-0.05	-0.06	-0.16	-0.10
Molasses	0.55	0.10	1.04	0.01	-0.12	-0.10
Gasoline-91	2.40	2.36	1.46	1.38	-0.57	-0.83
Gasoline-95	-1.02	-0.83	-1.42	-1.35	-1.63	-1.19
Diesel	0.84	1.02	0.46	0.54	-2.78	-1.62
Gasohol-91	0.55	-1.68	0.06	-1.32	0.48	-0.52
Gasohol-95	14.63	13.47	16.54	15.18	-0.22	-0.69
B2	0.61	0.76	0.33	0.41	22.30	27.11
B5	0.50	0.67	0.26	0.36	-98.60	-98.59
Palm oil	0.03	0.18	0.01	0.08	3.90	14.98
Tapioca products	-0.11	0.62	-0.12	2.92	-0.23	-0.18
Biodiesel	0.56	0.72	0.30	0.39	79.60	86.37
Ethanol	50.50	9.74	77.05	54.71	-0.08	-0.73
- Cassava-Ethanol	278	68.23	406	390	-0.11	-5.51
- Molasses- Ethanol	13.54	0.24	23.58	0.11	-0.07	0.05
Food Manufacturing	-0.01	0.11	-0.01	0.02	-0.19	-0.03
Road Transportation	0.06	0.30	0.03	0.16	-1.07	0.10
Private Transportation	-0.56	-0.62	-0.27	-0.32	-0.89	-0.14
Sectoral price:						
Cassava	2.00	-0.01	2.95	0.03	0.00	0.11
Sugar cane	0.05	-0.04	0.11	0.01	0.33	0.10
Oil palm	0.04	-0.06	0.01	0.00	15.77	0.10
Other crops	-0.18	-0.04	-0.10	0.01	-0.12	0.13
Molasses	4.32	-0.02	8.12	0.02	0.02	0.11
Gasoline-91	5.69	4.73	3.70	3.06	5.65	2.01
Gasoline-95	-7.74	-7.71	-7.56	-7.61	1.26	0.57
Diesel	-0.59	-0.66	-0.34	-0.34	-3.41	-1.18
Gasohol-91	3.37	4.34	2.14	2.81	5.19	1.85
Gasohol-95	3.40	4.34	0.34	1.65	5.20	1.85
B2	-0.57	-0.65	-0.32	-0.33	10.02	-0.05
B5	-0.53	-0.62	-0.30	-0.32	9.04	-1.10
Palm oil	0.07	-0.04	0.04	0.00	10.55	0.05
Tapioca products	1.20	-0.03	1.78	0.01	0.10	0.08
Biodiesel	0.40	-0.04	0.21	-0.01	181	0.05
Ethanol	-22.31	-0.03	-15.13	0.01	0.05	0.07
Food Manufacturing	0.00	-0.04	0.00	-0.01	0.09	0.03
Road Transportation	0.01	-0.26	0.01	-0.12	1.43	-0.01
Private Transportation	1.56	1.49	0.76	0.81	2.58	0.70
Cultivated land use:						
Cassava	4.21	1.23	6.04	6.26	0.01	-0.39
Sugar cane	0.20	0.12	0.23	-0.01	0.38	-0.30
Oil palm	0.00	0.16	0.00	0.03	0.00	14.43
Other crops	-0.06	-0.02	-0.08	-0.08	-0.01	-0.27

Table 7 (Cont'd)

Impacts	Policy A		Policy B		Policy C	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Sectoral exports:						
Molasses	-16.15	0.12	-27.76	-0.07	-0.19	-0.45
Gasoline-91	-1.84	-1.57	-1.26	-1.15	-2.65	-1.09
Gasoline-95	33.43	33.38	32.56	32.85	-4.36	-2.02
Diesel	2.09	2.40	1.17	1.23	13.11	4.27
Palm oil	-0.32	0.18	-0.17	0.02	-34.55	-0.23
Tapioca products	-4.69	0.16	-6.83	-0.02	-0.36	-0.35
Ethanol	204	0.13	106	-0.03	0.43	-0.30
Sectoral imports:						
Crude oil	1.05	1.19	0.58	0.63	-1.97	-1.34
Raw natural gas	-0.02	-0.05	0.00	-0.01	1.79	0.16
LPG	-0.30	-0.29	-0.21	-0.14	8.45	0.80
Electricity	0.00	-0.05	0.02	0.00	3.95	0.15
Coal	-0.05	-0.03	-0.02	-0.01	2.15	0.07
Palm oil	0.05	0.07	0.02	0.02	9.50	0.48
Sectoral employment:						
Cassava	4.01	1.17	5.97	6.25	-0.40	-0.18
Sugar cane	0.02	0.06	0.16	-0.02	-0.03	-0.09
Oil palm	-0.05	0.09	-0.05	0.02	15.71	14.67
Other crops	-0.24	-0.09	-0.15	-0.09	-0.41	-0.06
Sugar refinery	0.22	0.05	0.55	-0.04	-0.21	-0.12
Petroleum refinery	3.95	1.13	2.13	0.58	-6.75	-1.35
Palm oil	0.10	0.14	0.05	0.04	17.37	14.96
Tapioca products	-0.39	0.56	-0.42	2.88	-0.27	-0.20
Biodiesel	2.65	0.68	1.40	0.35	770	86.32
Cassava-Ethanol	95.32	68.16	251	390	-0.29	-5.53
Molasses-Ethanol	-31.33	0.19	-12.10	0.08	-0.23	0.03
Mining	-0.37	-0.03	-0.24	-0.08	-0.57	-0.16
Construction	0.02	0.06	0.02	0.01	0.04	-0.03
Road Transportation	0.05	0.16	0.03	0.07	-0.57	0.06
Sectoral Capital stock:						
Cassava	0.00	1.21	0.00	6.29	0.00	-0.15
Sugar cane	0.00	0.11	0.00	0.03	0.00	-0.05
Oil palm	0.00	0.16	0.00	0.08	0.00	14.71
Other crops	0.00	-0.04	0.00	-0.05	0.00	-0.03
Sugar refinery	0.00	0.11	0.00	0.01	0.00	-0.10
Petroleum refinery	0.00	0.22	0.00	0.09	0.00	-0.12
Palm oil	0.00	0.19	0.00	0.09	0.00	14.99
Tapioca products	0.00	0.63	0.00	2.93	0.00	-0.17
Biodiesel	0.00	0.73	0.00	0.40	48.70	86.38
Cassava-Ethanol	500	68.24	500	390	0.00	-5.51
Molasses-Ethanol	38.70	0.24	38.70	0.12	0.00	0.06
Road Transportation	0.00	0.31	0.00	0.16	0.00	0.10
Sectoral Capital rental:						
Cassava	8.44	-0.03	12.51	-0.01	-0.51	0.02
Sugar cane	0.22	-0.03	0.45	-0.01	-0.19	0.02
Oil palm	0.12	-0.04	0.02	-0.01	37.17	0.03
Other crops	-0.33	-0.03	-0.22	-0.01	-0.84	0.02
Sugar refinery	0.75	-0.03	1.45	-0.01	-0.72	0.02
Petroleum refinery	0.23	-0.04	0.12	-0.01	-1.64	0.03
Palm oil	0.42	-0.03	0.21	-0.01	43.31	0.02
Tapioca products	-0.75	-0.03	-0.97	-0.01	-1.55	0.02
Biodiesel	6.07	-0.03	3.20	-0.01	3,646	0.02
Cassava-Ethanol	-93.03	-0.03	-69.76	-0.01	-0.54	0.02
Molasses-Ethanol	-79.29	-0.03	-63.21	-0.01	-0.35	0.02
Road Transportation	1.18	-0.04	0.68	-0.01	-16.93	0.03

4.1.2 Sectoral impacts

The policy of reducing gasoline-95 use by 100 percent has considerable impacts at the sectoral level. For example, the price of gasoline-95 declines by 7.7 percent, while the demand for gasohol-95 grows by about 15 percent. Ethanol output increases by one-half due to a 278 percent increase in cassava-based ethanol and a 13.5 percent increase in molasses-based ethanol. This causes the prices of cassava and molasses to increase by 4.3 and 2.0 percent, respectively. Consequently, the price of ethanol declines by 22 percent. On the other hand, the prices of gasohol (91 and 95) increase by 3.4 percent due to a 5.7 percent rise in the price of gasoline-91, which is the main raw material in gasohol production.

Abandoning the domestic gasoline-95 use increases the export of gasoline-95 by over 30 percent. Also, there is a two-fold increase in the export of ethanol due to a huge increase in the number of ethanol plants, while due to a higher domestic molasses use the export of molasses decreases by 16 percent. Most sectoral imports show insignificant changes, with the exception of crude oil imported by the petroleum refinery industry, which increases by 1.1 percent probably due to an increase in non-gasoline-95 use.

We also observe a doubling of employment in the cassava-based ethanol industry, while employment in the molasses-based ethanol industry declines by a third. In addition, employment in the cassava, petroleum refinery, and biodiesel industries show moderate increases ranging from 2.7 to 4.0 percent.

The long-run impacts at the sectoral level are mostly in the same direction as in the short-run scenario for most of the industries, except that the magnitudes are smaller. For instance, ethanol output increases by 9.7 percent mostly due to a 68 percent increase in cassava-based ethanol, even though gasohol-95 use increases by 13.5 percent, which is slightly less than the figure in the short-run scenario. The prices of ethanol cassava, sugar cane, and molasses are almost unchanged. However, prices of gasohol-91 and gasohol-95 increase by 4.3 percent since the price of gasoline-91 increase 4.7 percent as in the short-run simulation. As a result, the cost of private transportation increases by 1.5 percent leading to a decline in private transportation of 0.62 percent.

From these results we can conclude that a policy of based solely on abandoning gasoline-95 use will be inadequate to support the two ethanol-based industries – cassava and molasses - in the short-run situation as there will be a massive decline of 93 and 79 percent, respectively, in their capital rentals.

4.2 Effects of Policy B: Promoting E20 Gasohol Use – 50 percent increase in ethanol content in gasohol-95 combined with Policy A

4.2.1 Macroeconomic impacts

A policy of promoting E20 gasohol-95 use combined with abandoning gasoline-95 use (i.e. Policy A) has almost no impact on the macro economy in the short-run. Real GDP is stable due to the balance of trade unchanged. Both real exports and real imports slightly increase by 0.08 percent resulting in a very slight decline in the terms of trade (Table 7, column B). Aggregate employment declines by only 0.01 percent, while the CPI increases by 0.08 percent. Furthermore, the revenue from fuel taxes drops by 1,681 million baht.

However, in the long-run, we observe slight positive impacts as was the case for Policy A. Real GDP grows 0.03 percent due to the fact that aggregate investment grows strongly by 0.03 percent and the balance of trade improves. However, both real household and government consumption shrink by 0.02 percent. There is a small increase of 0.07 percent in the CPI, while the average real wage remains stable. In addition the terms of trade decreases by 0.04 percent and the revenue from fuel taxes drops by 1,604 million baht.

4.2.2 Sectoral impacts

The short-run impacts are similar to Policy A in terms of the direction of the impacts, but the magnitudes are slightly higher. For instance, total gasohol-95 use grows by 16.5 percent (compared with 14.6 percent in Policy A), while the price of gasoline-95 decreases by 7.6 percent. Ethanol output soars by around three-quarters due to a four-fold increase in cassava-based ethanol and approximately a one-quarter increase in molasses-based ethanol, leading to price increases of 2.9 and 8.1 percent, respectively, for cassava and molasses. As a consequence, the price of ethanol drops by 15 percent. However, the prices of gasohol-91 and gasohol-95 increase by 2.1 and 0.34 percent, respectively, because the price of gasoline-91 increases by 3.7 percent. Due to the expansion of the cassava-based ethanol industry cassava output increases by 3.8 percent, leading to a 6.0

percent increase in land use for cassava farming, while prices and outputs of other sectors remain stable.

Policy B results in the growth of export of gasoline-95 by a third, similar to the result in Policy A. The export of ethanol doubles because of an excess of ethanol, while the export of molasses decreases by 27.8 percent because of a shortage of molasses. Most sectoral imports show insignificant changes except that the import of crude oil increases by 0.58 percent.

Employment in the cassava-based ethanol industry increases by 2.5 times, the molasses-based ethanol industry layoffs workers by 12 percent. In addition, employment in the cassava and petroleum refinery industries show modest increases of 6.0 and 2.1 percent, respectively, while employment in the tapioca products industry decline by 0.42 percent.

As was the case for Policy A, we find that Policy B is also not sufficient to relieve the two ethanol industries' losses in the short-run period as their capital rentals slump by 70 and 63 percent, respectively.

The long-run and short-run impacts of Policy B show almost similar results. In addition, the long-run impacts of Policy B on most sectors are smoother than that of Policy A. However, some sectors show much higher impacts. For instance, ethanol output increases by 55 percent due to a 390 percent increase in cassava-based ethanol. Consequently, the demand for cassava increases by 6.3 percent leading to an equal increase in land use for cassava production.

Exports of gasoline-95 grow by a third similarly to the short-run scenario, while imports show insignificant changes. The largest increase in employment of 390 percent is observed for the cassava-based ethanol industry, while employment rates in the other sectors remain stable except that employment in the cassava and tapioca products industries increase by 6.3 and 2.9 percent, respectively. Employment in each sector changes move in tandem with the change in its capital stock. For example, capital stock in the cassava-based ethanol industry rises by 390 percent.

4.3 Effects of Policy C: Replacing B2 with Unsubsidized B5 – a 100 percent reduction in B5 and a 150 percent increase in biodiesel content in B2

4.3.1 Macroeconomic impacts

The policy of replacing B2 with unsubsidized B5, represented by a 100 percent decline in B5 and a 150 percent increase in biodiesel content in B2 has a slightly negative impact on the macro economy. The overall impact is more adverse than was observed with the previous two policies. Real GDP declines by 0.08 percent due to a larger decline in the balance of trade. Inflation in this case is relatively moderate with a 0.37 percent increase in the CPI (Table 7, column C). Also, aggregate employment declines slightly by 0.10 percent. Furthermore, the revenue from fuel taxes substantially increases by 9,936 million baht due to abandoning subsidized B5.

As was the case with the previous policies, in the long-run we observe positive impacts on real output. In the case, real GDP grows 0.02 percent due to the fact that real household and government consumption increases by 0.08 percent, and export growth is marginally larger than the import growth, although aggregate investment drops by 0.02 percent. There is a 0.10 percent increase in the CPI, while the real wage drops slightly by 0.01 percent. The revenue from fuel taxes increases by 6,986 million baht which is about two-thirds of the change in the short-run scenario.

4.3.2 Sectoral impacts

Overall, more sectors of the economy are adversely affected by this policy in the short-run than was the case with the previous policies. For example, with the exception of biodiesel (80 percent increase), unsubsidized B5 (22 percent increase), palm oil (3.9 percent increase), oil palm (3.6 percent increase) and gasohol-91 (0.48 percent increase), all other sectors contract at various rates ranging from 0.07 percent (molasses-based ethanol) to 2.8 percent (diesel). The price of biodiesel rockets by 181 percent, leading to a considerable rise in the price of unsubsidized B5 which increases by 10 percent. Consequently, we find that total mixed-biodiesel use declines by about 4.8 percent (authors' calculation), though unsubsidized B5 use grows by 22 percent.

There are significant short-run impacts on some international trade sectors. The largest impact on the export sector is observed for palm oil exports, which fall by one-third, while diesel exports increase by 13 percent. Furthermore, the policy increases imports of, palm oil and LPG by 9.5 and 8.5 percent, respectively, while crude oil imports decrease by 2.0 percent. In line with the decline in sectoral output, employment in all sectors contract with the exception of oil palm, palm oil, and biodiesel. Employment in these three industries increases by 16, 17, and 770 percent, respectively. In contrast, we observe contractions ranging from 0.03 percent (sugar cane) to 6.8 percent (petroleum refinery).

In the long-run, it can be seen that this policy adversely affects on the output of nearly all the sectors, similar to the results in the short-run. For example, with the exception of biodiesel (86 percent increase), unsubsidized B5 (27 percent increase), oil palm and palm oil (15 percent increase), road transportation (0.10 percent increase), and molasses-based ethanol (0.05 percent increase), all other sectors shrink. All commodity prices show little change, which are different from the results in the short-run. For instance, the price of unsubsidized B5 decreases by only 0.05 percent (compared with 10 percent increase in the short-run scenario). Consequently, total mixed-biodiesel use drops by only 1.0 percent compared to 4.8 percent in the short run simulation.

International trade sectors are slightly affected in the long-run. The largest impact on the export sector is observed for diesel exports, which increase by 4.3 percent. In addition, the policy reduces crude oil imports by 1.3 percent, while LPG imports increase by 0.8 percent. Employment and capital stock in each sector vary in accordance with the corresponding output change. For example, both employment and capital stock in the oil palm industry increase by 15 percent. Consequently, land use for oil palm production increases by the same percentage, while land use for other crop farming is reduced by only 0.27 percent.

A one-off replacement of B2 with unsubsidized B5 drives up capital rentals in the biodiesel industry by 36 times in the short-run. The palm oil and oil palm industries are also the big gainers whose capital rentals increase by 43 and 37 percent, respectively. The biggest loser is the road transportation, whose capital rentals declines by 17 percent. These results indicate that it would be more prudent for the government to implement this measure gradually. For example, there could be a phased policy whereby B2 is replaced with B3 in year 1, B3 with B4 in year 2, and B4 with B5 in year 3.

5. Summary and Policy Implications

The objectives of this study were to develop a CGE model of Thailand's economy and to use it to analyse the macroeconomic and sectoral impacts of implementing biofuel-promoting measures contained in the Thai government's 15-year renewable energy development plan. The series of bio-liquid fuel promotion strategies investigated were abandoning gasoline-95 use, promoting E20 gasohol-95 use, and replacing B2 with unsubsidized B5. The study also analysed the feasibility of the targets set under the plan. The following simulations were conducted to capture these policy objectives: Policy A, a 100 percent decline in gasoline-95 use in all sectors except the petroleum refinery industries; Policy B, a 50 percent increase in ethanol content in gasohol-95 combined with Policy A; and Policy C, a 100 percent decrease in B5 use in all sectors and a 150 percent increase in biodiesel content in B2 (transition from B2 to B5). The study results indicate that, in general, all the bio-liquid fuel promoting policies are likely to have an adverse impact on real output in the short-run, leading to a decline in aggregate employment. However, in the long-run, there is a positive impact on real GDP via an increase in aggregate investment resulting from an increase in domestic saving, an improvement in the trade balance, and a general increase in sectoral output.

In terms of the relative impacts of the three policies, Policy B results in the greatest improvement in real output, while Policy C has the largest decline in employment across the board. In terms of ethanol promotion, Policy B has a larger impact on the economy than Policy A since all ethanol promotion strategies are implemented. To reach the target, ethanol use must increase by 234 percent by 2011. However, Policy B causes an increase in ethanol use by 77 percent in the short-run and 55 percent in the long-run. This indicates that only abandoning gasoline-95 and promoting E20 gasohol-95 use are not adequate to achieve the target. The government might reduce its target or provide more ethanol promotion strategies such as abandoning gasoline-91 and an increase in the gasohol subsidy. Nevertheless, the government might not have the budgetary capacity to support ethanol promotion since the results of this study show that implementing Policy B causes a moderate decrease in the fuel tax revenue. In addition, the results of the study suggest that abandoning gasoline-95 use should be implemented together with promoting E20 gasohol-95.

The study has shown that replacing B2 with unsubsidized B5 provides an increase in biodiesel use of 80 percent in the short-run and 86 percent in the long-run. This policy fails to achieve the biodiesel target in which biodiesel use must increase by 176 percent by 2011. Therefore, Additional biodiesel promotion policies such as promoting B10 use need to be implemented. Furthermore, replacing B2 with unsubsidized B5 (which means abandoning the B5 subsidy), allows the revenue from fuel taxes to increase considerably. The government could therefore use this revenue to subsidize the price of B5 in order to boost biodiesel use. This issue needs to be investigated in further work. In addition, it would be desirable to phase the implementation over 2 years (or more) since in the long-run scenario the biodiesel price is lower. Otherwise the price of biodiesel could be too costly in the short-run, resulting in a marked increase in mixed-biodiesel prices which consequently affects transportation sectors who are the main mixed-biodiesel users.

The model developed in this study provides some useful insights into the possible impacts of the Thai government's bio-liquid promotion policy. However, it is a static model which provides limited information on the adjustment of the relevant variables over time. Further work will concentrate on introducing some dynamics into the model in order to measure the impacts of implementing the energy policies at different points in time. Further work will also be done on the econometric estimation of the behavioral parameters used in the model. Finally, it would be useful to incorporate carbon emissions in future work, given concerns over climate change and the need to consider how Thailand could benefit from carbon credits.

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Appendix 1: Definition of I-O Codes in the Input-Output Table of Thailand

IO codes	Definitions	I-O codes	Definitions
001	Paddy	056	Confectionery & Snack
002	Maize	057	Ice
003	Other Cereals	058	Monosodium Glutamate
004	Cassava	059	Coffee & Cocoa & Tea Processing
005	Other Root Crops	060	Other Food Products
006	Beans and Nuts	061	Fish Meal & Animal Feed
007	Vegetables	062	Distilling & Blending Of Spirit
008	Fruits	063	Breweries
009	Sugar Cane	064	Soft Drinks & Carbonated Water
010	Coconut	065	Tobacco Processing
011	Palm Nut And Oil Palm And Oil Palm	066	Tobacco Products
012	Kenaf And Jute	067	Spinning
013	Crops for Textile and Matting	068	Weaving
014	Tobacco	069	Textile Bleaching, Printing & Finishing
015	Coffee and Tea	070	Made-Up Textile Goods
016	Rubber	071	Knitting
017	Other Agricultural Products	072	Wearing Apparels
018	Cattle And Buffalo	073	Carpets And Rugs
019	Swine	074	Jute Mill Products
020	Other Livestock	075	Tannery And Leather Finishing
021	Poultry	076	Leather Products
022	Poultry Products	077	Foot Wear, Except Of Rubber
023	Silk Farming	078	Saw Mill & Wooden Construction Materials
024	Agricultural Services	079	Wood And Cork Products
025	Logging	080	Wooden Furniture & Fixture
026	Charcoal and Firewood	081	Paper And Paper Board
027	Other Forestry Products	082	Paper & Paperboard Products
028	Ocean And Coastal Fishing	083	Printing & Publishing
029	Inland Water Fishing	084	Basic Chemicals
030	Coal And Lignite	085	Fertilizer, Pesticide And Insecticide
031	Crude Oil & Natural Gas	086	Petrochemical Products
032	Iron Ore	087	Paint
033	Tin Ore	088	Drug And Medicine
034	Tungsten Ore	089	Soap & Cleaning Preparations
035	Other Non-Ferrous Metal Ore	090	Cosmetic
036	Fluorite Ore	091	Matches
037	Natural Chemical & Fertilizer	092	Other Chemical Products
038	Salt	093	Petroleum Refinery & Gas Separated Plant
039	Limestone	094	Other Coal & Petroleum Products
040	Stone Quarrying	095	Rubber Sheet & Block Rubber
041	Other Mining & Quarrying	096	Types And Tubes
042	Slaughtering	097	Other Rubber Products
043	Canning & Preserving Of Meat	098	Plastic Wares
044	Dairy Products	099	Ceramic And Earthen Wares
045	Canning & Preserving Of Fruits & Vegetables	100	Glass & Glass Products
046	Canning & Preserving Of Fish & Seafood	101	Structural Clay Products
047	Coconut and Palm Oil	102	Cement
048	Other Vegetable & Animal Oils	103	Concrete And Cement Products
049	Rice Milling	104	Other Non-Metallic Products
050	Flour & & Tapioca Milling	105	Iron And Steel
051	Grinding Corn	106	Secondary Steel Products
052	Flour & Other Grain Milling	107	Non-Ferrous Metal
053	Bakery And Other	108	Cutlery And Hand Tools
054	Noodle & Similar Products	109	Metal Furniture & Fixture
055	Sugar Refineries	110	Structural Metal Products

Appendix 1: (Cont'd)

IO codes	Definitions	IO codes	Definitions
111	Other Fabricated Metal Products	161	Life Insurance Service
112	Engine And Turbine	162	Other Insurance Service
113	Agricultural Machinery & Equipment	163	Real-estate
114	Wood & Metal Working Machine	164	Business Service
115	Special Industrial Machinery	165	Public Administration
116	Office Equipment & Machinery	166	Sanitary & Similar Services
117	Electrical Industrial Machinery & Appliances	167	Education
118	Radio, Television Set & Communication Equipment	168	Research
119	Others Electric Appliances	169	Hospital
120	Insulated Wire And Cable	170	Business & Labor Associations
121	Electric Accumulator & Battery	171	Other Community Services
122	Other Electrical Apparatuses & Supplies	172	Motion Picture Production
123	Ship Building	173	Movie Theater
124	Railway Equipment	174	Radio, Television & Related Services
125	Motor Vehicle	175	Library And Museum
126	Motorcycle & Bicycle & Other Carriages	176	Amusement & Recreation
127	Repairing Of Vehicle	177	Repairing, Not Elsewhere Classified
128	Aircraft	178	Personal Services
129	Scientific Equipments	180	Unclassified
130	Photographic & Optical Goods	190	Total Intermediate Transaction
131	Watches And Clocks	201	Wages and Salaries
132	Jewelry & Related Articles	202	Operating Surplus
133	Recreational & Athletic Equipment	203	Depreciation
134	Other Manufacturing Goods	204	Indirect Taxes less Subsidies
135	Electricity	209	Total Value Added
136	Pipe Line	210	Control Total
137	Water Supply System	301	Private Consumption Expenditure
138	Residential Building Construction	302	Government Consumption Expenditure
139	Non-Residential Build Construction	303	Gross Fixed Capital Formation
140	Public Works For Agriculture & Forestry	304	Increase in Stock
141	Non-Agricultural Public Works	305	Exports (F.O.B.)
142	Construction Of Electric Plant	306	Special Exports
143	Construction Of Communication Facilities	309	Total Final Demand
144	Other Constructions	310	Total Demand
145	Wholesale Trade	401	Imports (C.I.F.)
146	Retail Trade	402	Import Tax
147	Restaurant & Drinking Place	403	Import Duty
148	Hotel And Lodging Place	404	Special Imports
149	Railways	409	Total Imports
150	Route & Non route of Road Passenger Transport	501	Wholesale Trade Margin
151	Road Freight Transport	502	Retail Trade Margin
152	Land Transport Supporting Services	503	Transportation Cost
153	Ocean Transport	509	Total Margin and Transportation Cost
154	Coastal & Inland Water Transport	600	Control Total
155	Water Transport Services	700	Total Supply
156	Air Transport		
157	Other Services		
158	Silo And Warehouse		
159	Post And Telecommunication		
160	Banking Service		

Appendix 2: Elasticity Parameters

	Industry	Energy-Capital Substitution	CET Output Substitution
1	Cassava	0.32	0.5
2	Sugarcane	0.30	0.5
3	Oil Palm	0.23	0.5
4	Other Crops	0.22	0.125
5	Charcoal and Firewood	0.07	0.5
6	Rice Milling	0.16	0.01
7	Sugar Refineries	0.09	0.125
8	Petroleum and Natural Gas	0.29	0.25
9	Natural Gas Processing	0.05	0.25
10	Petroleum Refinery	0.12	0.25
11	Gasohol-91	0.5	0.5
12	Gasohol-95	0.5	0.5
13	B2	0.5	0.5
14	B5	0.5	0.5
15	Main Electricity	0.06	0.5
16	Hydro Power	0.5	0.5
17	SPPP	0.16	0.5
18	VSPP	0.16	0.5
19	Coal	0.24	0.5
20	Palm Oil	0.11	0.5
21	Tapioca Milling	0.12	0.5
22	Biodiesel	0.10	0.5
23	Molasses-Ethanol	0.12	0.5
24	Cassava-Ethanol	0.10	0.5
25	Livestock	0.15	0.5
26	Forestry	0.40	0.5
27	Fishery	0.20	0.5
28	Mining and Quarrying	0.14	0.5
29	Food Manufacturing	0.12	0.5
30	Beverages and Tobacco	0.09	0.5
31	Textile Industry	0.14	0.5
32	Wood and Furniture	0.16	0.5
33	Paper Products and Printing	0.11	0.01
34	Chemical and Rubber	0.13	0.5
35	Non-Metallic Products	0.08	0.5
36	Basic Metal	0.12	0.5
37	Fabricated Metal Products	0.13	0.5
38	Machinery	0.11	0.5
39	Other Manufacturing	0.15	0.5
40	Construction	0.18	0.5
41	Wholesale Trade	0.07	0.5
42	Retail Trade	0.07	0.5
43	Rail Transportation	0.34	0.5
44	Road Transportation	0.06	0.5
45	Water Transportation	0.12	0.5
46	Air Transportation	0.13	0.5
47	Public Services	0.40	0.5
48	Other Services	0.12	0.5
49	Unclassified	0.12	0.5
D1	Private Transportation	0.5	0.5
D2	Government Transportation	0.5	0.5

Appendix 2: (Cont'd)

	Commodity	Armington Substituiton	Export Elasticities	CRESH Inter-Fuel Substitution*	
				Household	Government
1	Cassava	3.25	4.4	-	-
2	Sugarcane	2.7	4.4	-	-
3	Oil Palm	2.45	4.4	-	-
4	Other Crops	3.32	4.4	-	-
5	Agricultural Residue	3.32	4.4	1.50	1.50
6	Charcoal	2.5	5.6	1.35	1.50
7	Firewood	2.5	5.6	1.44	1.50
8	Milled Rice	2.6	4.4	-	-
9	Paddy Husk	2.6	4.4	1.50	1.50
10	Sugar	2.7	4.4	-	-
11	Molasses	2.7	4.4	-	-
12	Bagasse	2.7	4.4	1.50	1.50
13	Crude Oil	5.2	5.6	-	-
14	Raw Natural Gas	2.8	5.6	-	-
15	Condensate	5.2	5.6	-	-
16	Natural Gasoline and Others	5.2	5.6	-	-
17	Processed Natural Gas	2.8	3.8	1.50	1.50
18	LPG	2.8	3.8	1.31	1.34
19	Gasoline-91	2.1	3.8	1.50	1.50
20	Gasoline-95	2.1	3.8	1.50	1.50
21	Diesel	2.1	3.8	1.50	1.50
22	Jet Fuel	2.1	3.8	1.50	1.50
23	Fuel Oil	2.1	3.8	1.50	1.50
24	Other Petroleum Products	2.1	3.8	1.50	1.50
25	Gasohol-91 (E10)	2.1	3.8	1.50	1.50
26	Gasohol-95 (E10)	2.1	3.8	1.50	1.50
27	B2	2.1	3.8	1.50	1.50
28	B5	2.1	3.8	1.50	1.50
29	Electricity	2.8	5.6	0.90	0.66
30	Coal	3.05	5.6	1.50	1.50
31	Palm Oil	3.3	4.4	-	-
32	Tapioca Products	2	4.4	-	-
33	Biodiesel (B100)	2.1	4.4	-	-
34	Ethanol	2.1	4.4	-	-
35	Livestock	4.33	5.6	-	-
36	Forestry	2.5	5.6	-	-
37	Fishery	1.25	5.6	-	-
38	Mining and Quarrying	0.9	5.6	-	-
39	Food Manufacturing	2	4.4	-	-
40	Beverages and Tobacco	1.15	6.2	-	-
41	Textile Industry	3.75	4.4	-	-
42	Wood and Furniture	3.4	5.6	-	-
43	Paper Products and Printing	2.95	3.6	-	-
44	Paper Production Residues	2.5	4.4	1.5	1.5
45	Chemical and Rubber Products	3.3	3.8	-	-
46	Non-Metallic Products	2.9	5.6	-	-
47	Basic Metal	2.95	5.6	-	-
48	Fabricated Metal Products	3.83	5.6	-	-
49	Machinery	3.96	6.7	-	-
50	Other Manufacturing	2.8	5.6	-	-
51	Construction	1.9	3.8	-	-
52	Wholesale Trade	1.9	3.8	-	-
53	Retail Trade	1.9	3.8	-	-
54	Rail Transportation	1.9	3.8	-	-
55	Road Transportation	1.9	3.8	-	-
56	Water Transportation	1.9	3.8	-	-
57	Air Transportation	1.9	3.8	-	-
58	Public Services	1.9	3.8	-	-
59	Other Services	1.9	3.8	-	-
60	Unclassified	1.9	3.8	-	-
D1	Private Transportation	1.9	3.8	-	-
D2	Government Transportation	1.9	3.8	-	-

Note: These CRESH elasticities were obtained using the formula, $\sigma_{ij} = 1.5 - s_{ij}$, where σ_{ij} is CRESH elasticity parameters of substitution of energy *i* in sector *j*, while s_{ij} is energy use share of energy *i* in sector *j*. Other CRESH elasticities were also obtained in the same way.

Appendix 3: Consumption and Definition of Bio-Liquid Fuels

Fuel Type	Final Consumption in 2008 (million liters) [1/]	Explanation
Gasoline-91	3,388	Gasoline-91 is also known as regular gasoline. The number 91 indicates the level of octane.
Gasoline-95	341	Gasoline-95 is also known as premium gasoline. The number 95 indicates the level of octane.
Gasohol-91 (E10)	924	Gasohol-91 (E10) is a fuel mixture of 10 percent ethanol and 90 percent gasoline. The number 91 indicates the level of octane.
Gasohol-95 (E10)	2,439	Gasohol-95 (E10) is a fuel mixture of 10 percent ethanol and 90 percent gasoline. The number 95 indicates the level of octane.
Gasohol-95 (E20)	29	Gasohol-95 (E20) is a fuel mixture of 20 percent ethanol and 80 percent gasoline. The number 95 indicates the level of octane.
B2	13,300 [2/]	B2 or B2-biodiesel is a fuel mixture of 2 percent biodiesel (B100) and 98 percent diesel. The number 2 indicates the content of biodiesel.
B5	3,780	B5 or B5-biodiesel is a fuel mixture of 5 percent biodiesel (B100) and 95 percent diesel. The number 2 indicates the content of biodiesel.

Note: 1/ The figures were obtained from DEDE (1981-2009).
2/ The figure was estimated by the authors.