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A Comprehensive Framework for Analysing Long-term Energy Scenarios for Thailand

Srichattra Chaivongvilan*[1] and Deepak Sharma*

Abstract – *Energy is one of the most critical ingredients for economic development and prosperity of any nation. It is more so for a developing country like Thailand where energy is critically needed in order to realize the economic growth aspirations of the country. The task of providing adequate and reliable energy has however emerged as a challenging policy issue for Thailand, particularly when viewed in the context of the evolving socio-economic dynamics of the country, typified by an energy sector that is in the throes of reform, resource scarcity, energy dependence, industrial development and high economic growth. In order, therefore, to satisfy the expected energy requirements and sustain economic prosperity, effective national energy policies would be needed. A review of the existing energy policies suggests that these policies are somewhat narrow, fragmented and insular. They therefore are unlikely to be able to satisfactorily meet the energy needs of Thailand. This deficiency could however – this paper contends – be overcome by taking a fresher perspective on the nature of policy challenges and strategies to redress them. Such a perspective, this paper further argues, could be assisted by adopting a comprehensive framework that could accommodate the specificities of Thailand while integrating the technical, economic, environmental and political dimensions of the energy sector in a cohesive and consistent manner. This paper is an early attempt at developing such a framework.*

Keywords – Energy frameworks, energy system, long-term, scenarios, Thailand.

1. INTRODUCTION

Energy is vital for the social and economic well-being of a nation. It is more so for a developing country like Thailand where energy is necessary for raising the standard of living, from subsistence to economically prosperous levels. The energy use in Thailand has increased rapidly over the past three decades, with an average annual growth rate of 7.2% over the period 1973-2005. Further, the primary energy requirements are expected to grow at an annual rate of 4.5% over the next 20 years [1]. This increased energy requirement is necessary to support the economic development process; the Thai economy is estimated to grow at an average annual rate of 4% to the year 2025 [1]. In view of the limited domestic resource availability, much of the future energy needs are expected to be obtained from overseas – partly from neighboring countries and mainly from the politically volatile regions, for example, the Middle East. The economic consequences of these imports are likely to be significant, for example, they would contribute to a worsening of the balance of payment situation of the country, especially in view of rising global energy prices.

Additionally, there would be considerable environmental, societal, and political impacts [2].

A balanced set of energy policies will therefore be required in order to provide a satisfactory redress to the issues that are likely to emerge at the interface of technical, economic, social, environmental, and political dimensions as noted above. The existing policies are indeed narrowly focused, insular, and limited in scope. They are also marked by their inherent contradictions, for example, while the privatisation policies could attract energy investments, they might also raise the ensuing issues of sovereignty and public acceptance [2]. From an institutional perspective – despite significant restructuring in the last ten years or so, the institutional policy settings are still essentially fragmented, opaque, and unstable [2]. Furthermore, the past energy policy practices in Thailand appear to have been dominated by centralised planning, assisted by conventional bottom-up modelling and a failure to include the wider economic interactional analysis. Even the modelling approach followed by the energy planning agency (namely, EPPO) appears to be technocratic, bottom up, and devoid of economic linkages [2]. This suggests that the existing energy policy framework and settings are unlikely to be able to provide a balanced redress of the economy-wide issues.

There is therefore a need for Thailand – one of the most energy intensive economies in Southeast Asia [3] – to carefully examine the relationship between energy and economy and its wider implications in the long-term. This is necessary for assisting the government to decide appropriate pathways for ensuring country's prosperity.

A number of long-term energy modelling studies have been conducted to examine the energy impacts in Thailand, for example [3], [4], [5] and [6]. However, they are solely focused on specific energy sectors, and specific analyses. The review of these models and studies – conducted in this paper – suggests that none of them is adequate in terms of providing comprehensive insights into the relationship between energy and the

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economy, and integrating technical, economic, environmental and political dimensions of energy sector development. This paper develops broad contours of a framework that could assist in developing such insights and integration. It also presents the assessment energy impacts of alternative scenarios based on an application of this framework.

The paper is divided into 6 sections. The first section discusses the need to develop a comprehensive energy framework for purpose of planning and long-term policy assessment. Section 2 gives a brief description of the energy situation in Thailand. Some details of the conventional and proposed methodological energy frameworks are discussed in the third section. Section 4 describes the broad contours of three alternative long-term energy scenarios for Thailand. The results of three scenarios to the year 2050 are presented and discussed in Section 5. Section 6 presents key conclusions and provides recommendations for further research.

2. THAILAND'S ENERGY SITUATION

This section of the paper provides an overview of the energy situation in Thailand. It is a prerequisite for developing appreciation for the country's energy issues, challenges, and strategies to address these challenges. Thailand has limited reserves of natural gas, lignite, crude oil and hydro. According to [3], for example, the availability of natural gas, lignite and crude-oil are estimated to be 102 million tons of oil equivalent (Mtoe), 152 Mtoe and 0.6 Mtoe respectively in the year 2030 [3]. Thailand has arguably significant potential to develop renewable energy, especially biomass. This non-commercial energy accounted for nearly 20% of total primary energy supply in the year 2005, and has a potential to increase its contribution in the future [7]. Further, other renewable sources currently contribute rather insignificantly to meeting overall energy needs. The demand however for energy far exceeds its availability as noted above. Consequently, Thailand essentially stays as an energy deficient economy. More than 60% of its commercial energy consumption is currently imported [7]. This has, ever since 1973, seriously impacted the country's economic trade balance [2].

2.1 *Energy production*

Table 1 shows the primary energy production of Thailand.

It shows that the rate of production has increased significantly since 1973, especially between the years 1980 and 1990 when it dramatically increased from 0.7 to 9.9 Mtoe. The main reason behind this growth was the exploration and discovery of domestic natural gas resources in the mid-1970s [8]. This slightly reduced Thailand's reliance on imported fuels. During the 1990s, the energy production increased from 9.9 Mtoe in 1990 to 29.3 Mtoe in 2000 – rising more than 30% in a decade [7], in order to support the economic expansion. Currently, indigenous production accounts for approximately 50% of total primary energy supply. It is estimated that if Thailand is to meet its energy needs from its own resources (*i.e.*, no imports). Therefore, the issue of national energy security has assumed added significance, viewed especially in the current context of increasing energy demand, and the rising global energy prices.

Table 1. Primary energy production (Mtoe) [7].

	1973	1980	1990	2000	2005
Crude oil	-	0.02	2.09	5.28	8.86
Natural gas	-	-	5.66	17.52	20.53
Lignite	0.12	0.37	1.10	5.15	5.98
Hydro	0.41	0.28	1.10	1.34	1.29
Total	0.53	0.68	9.95	29.28	36.66

2.2 *Energy demand*

The foregoing discussion illustrates the significance of long-term energy security issue for Thailand. This issue would appear even more critical when viewed in the backdrop of rising energy demand. Table 2 shows the total final energy consumption over the period 1973-2005. The final energy consumption increased significantly in the 1990s, from 21 Mtoe in the year 1990, to 48.3 Mtoe in the year 2000. This increase took place even though the economy was impacted by the 1997 financial crisis. Further, in the year 2005, the total energy consumption dramatically increased to 62.4 Mtoe – a growth of more than 75% compared with 2000. These statistics suggest that the rate of final energy consumption far exceeded the rate of indigenous production as shown in Table 1. Besides, the future energy demands are expected to increase to more than 120 Mtoe in the year 2030 [9]. This is mainly to support the economic expansion, urbanisation, industrialisation and social development [9]. The provision of adequate energy is clearly a major long-term energy challenges for Thailand.

2.3 *Other energy challenges*

In addition to the energy security challenge noted above, a previous study [2] had identified several other energy challenges for Thailand. These include i) mobilising adequate investments for energy development; ii) mitigation the environmental impacts of energy development; and iii) establishing an appropriate balance between economical, societal, and national and global political interests.

A satisfactory redress of these challenges would clearly require effective energy policies. Chaivongvilan *et al.* [2] also suggested that the existing energy policies would be inadequate to provide satisfactory redress for these challenges, because they are essentially fragmented, insular, sector- or issue-specific, and ignore wider implications in the national and global contexts (as also noted earlier in this paper). At the core of this problem is the fact that these policies are not supported by any consistent and coherent energy policy framework that takes into account a holistic view of the energy sector, including its intra- and inter-sectoral interactions, and its other relations with the rest of the economy. This paper proposes the broad contours of such a framework. This framework – it is argued – could be employed to analyse technical, economic, environmental, and societal impacts of alternative energy policy options in the long-term.

Table 2. Final energy consumption by sector (Mtoe) [7].

	1973	1980	1990	2000	2005
Industry	1.96	2.70	5.20	16.74	22.64
Transport	3.19	4.02	11.37	18.65	23.49
Agriculture	0.80	1.14	1.80	2.16	3.21
Residential and Commercial	0.53	1.53	2.53	3.53	4.53
Others	0.24	0.29	0.02	0.23	0.28
Total	6.69	9.09	21.02	48.34	62.40

3. METHODOLOGICAL FRAMEWORK

The key elements of the proposed framework include energy optimisation and energy-economy interaction models. This section provides an overview of the key features of the proposed framework.

3.1 Bottom-up model

The main purpose of the model is to determine the most appropriate technological and resource configuration to meet long-term energy needs of the nation under a set of pre-specified constraints. There has, over the years, been significant effort at developing such models by energy researchers around the world. The main energy optimisation models are Model for Energy Supply Strategy Alternatives and their General Environmental impacts (MESSAGE), Market Allocation model (MARKAL), The Long-range Energy Alternatives Planning model (LEAP), Energy and Power Evaluation Program (ENPEP), and others. These models are based on a bottom-up approach, which is based on the principle of Reference Energy System (RES) [10]. The concept of RES allows one to represent the entire energy network, including existing and future technologies from resources to end users in the form of networks consisting of nodes and directed pathways.

Energy Optimisation Model - MESSAGE

For this research, the selected optimisation model is MESSAGE. MESSAGE has been used extensively in the past three decades in global, regional, national, and sectoral setting for analysing energy systems (for example, [11], [12], and [13]). It was originally developed by the International Institute for Applied System Analysis (IIASA), and subsequently enhanced by the International Atomic Energy Agency (IAEA). The advantage of the MESSAGE model compared to other models is the flexibility to adjust the framework according to the limited data availability or the size of the focusing sector [14]. This model has been selected for analysing the long-term energy scenarios for Thailand due to the flexibility it allows for providing an exhaustive description of the energy system being modeled, from supply to demand [10]. This model has currently been employed by TINT, to analyse the future rote of technologies in a corporation on constrained world [13].

This model is designed to formulate and evaluate alternative energy supply strategies consonant with a set of policies, for example, limits on fuel availability, energy trade, market penetration rates, and environmental profiles [10]. The underlying principal of MESSAGE is the optimisation of an objective function under a set of constraints that define the problem. By supplying cost information and scenario features, and constraints, the model is able to provide the least-cost feasible solution of the energy system from the base year to the end of the study period.

The following brief formulation provides the broad description of the MESSAGE's objective function. The full mathematical formulation including constraints of this model is available in [10].

Objective function = MIN (∑ (Fixed costs × Available capacities) + (variable costs × Production) + (Investments in new capacities + other costs and expenses))

3.2 Top-down model

This model could be used to assess the economy-wide impacts of future technological/resource outcomes of energy optimisation model. The two main types of approaches for this purpose are general equilibrium analysis and partial equilibrium analysis. The general equilibrium analysis approach is based on the assumptions of perfectly competitive, deregulated markets. The partial equilibrium approach, on the other hand, allows for a co-habitation of market and planned segments in an economy. The general equilibrium models attempt to describe the entire economic system, while the partial equilibrium methodology focuses on a particular sector of the economy [15]. Both these approaches require disaggregated representation of the economy showing interactions between its various segments. Economic input-output framework is an example of such a disaggregated representation.

Input-output table

This paper proposes an input-output model for analysing economy-wide impacts of various energy configurations as identified by the application of optimisation model (as discussed above). This approach is capable of capturing the details of the activities at the sub-sectoral levels, along with the underlying interrelationships across the economy, such as investment, employment, and environment. It should also be noted that input-output approach and analytical tools based on this approach have been extensively applied for the analyses of a diverse range of policy questions over the last 40 years [16]. Tiwari [17] and Pachauri and Spreng [18], for example, employed input-output model to examine the linkages between energy and economy in terms of energy intensity and the roles of energy industry in the economy. The main reason for proposing input-output model in this paper is that this model can investigate complex interrelationships between energy, environment and economy, at both the macro level and the sectoral level.

Therefore, this model is particularly useful as it could capture impacts at the sectoral levels for example, at the level of energy technologies, unlike the other macroeconomic models [3]. Figure 1 provides a broad overview of the input-output framework employed in this research. This table shows the all transactions between sectors represented in monetary or physical units. Each sector’s production is consumed by intermediate sectors, and by final demand sector. For this purpose, the inter-industry segment of the table is modified to reflect the energy and other economic sectors. The objective of this modification is to determine how each type of energy configuration would impact the wider economy.

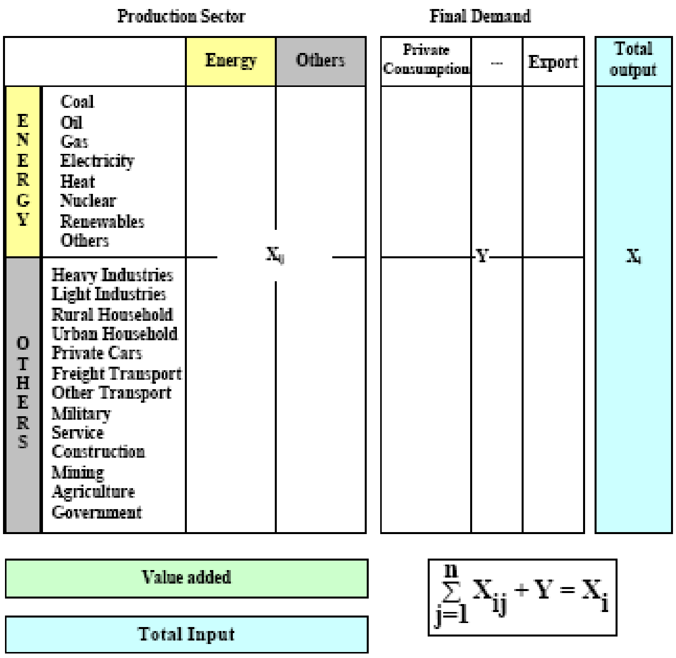

Fig. 1. Broad overview of input-output framework [11].

The energy impacts assessed through the bottom-up modelling are then translated into economic impacts. These economic impacts are assessed with the energy-oriented input-output model. This consequently becomes a comprehensive framework as the determination of economic impacts is assessed by using the output from the energy modelling to investigate how they would impact various economic sectors. For example, how changes in primary energy mix would impact total outputs, and employment in Thailand.

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4. LONG-TERM ENERGY SCENARIO

This paper proposes three alternative long-term scenarios, namely, i) Business-as-usual (BAU), which serves as a reference scenario in this research ; ii) Nuclear Power (NP) scenario, and iii) Renewable Energy (RE) scenario. These scenarios would also be informed by works of other researchers in Thailand, for example, the ongoing research in Thailand Institute of Nuclear Technology (TINT). This work is focused on analysing the impacts of nuclear power in the broader energy-mix in Thailand [13]. All three scenarios, BAU, NP and RE are based on different sets of technologies, constraints and policies. While the scope of NP focuses on the introduction of nuclear power, the scope of RE scenario is to increase the potential of renewable energy, for example, biomass, to the commercial energy system.

4.1 Data

The main data for BAU, NP and RE comprise energy demand, technologies, technological constraints, environmental profiles, and policy regulations. TINT [9] has forecasted the trend of future energy demands based mainly on the features summarised in Table 3. Beside energy demand, MESSAGE requires data on technological efficiencies, technical life time, investment cost, fixed cost, emission factors, and related activity and capacity boundaries. These parameters are required in the MESSAGE in order to optimise the energy investment decisions by finding the least-cost supply solution in long-term.

Table 3. Main features in energy scenarios.

Features	Descriptions
Economy	GDP growth rate (annual)
	– 4.5% per year for 2005-10
	– 5% per year for 2010-15
	– 5.8% per year for 2015-20
	– 5.5% per year for 2020-50
Energy	GDP of energy growth rate (annual)
	– 9% per year for 2005-2010
	– 5% per year for 2010-15
	– 7% per year for 2015-20
	– 6% per year for 2020-25
	– 5.5% per year for 2025-50
Demography	Population growth rate at an average 0.6% per year

4.2 RES specification

RES development is the core requirement for energy impact analysis. RES represents the current energy flows in the country from extraction, conversion, transmission and distribution, to final conversion for end users. The RES of Thailand – developed in this paper – consists of five energy forms, namely, resources, primary, secondary, final, and demand. The demand analysed in this study includes five main economic sectors, which are, industry, agriculture, service, transport and household. The main energy types and technologies in this RES are based on Thailand's 2005 energy balance table [7] and TINT [9]. The RES for Thailand (Figure 2) contains 209 technologies. With updates of technological data, this RES is a sound representation of the most technological base for the Thailand's current energy system.

5. RESULTS AND DISCUSSIONS

The future energy impacts are estimated in this paper for the three long-term energy-policy scenarios, namely, Business-as-usual (BAU), Nuclear Power (NP), and Renewable Energy (RE) – as discussed above. Select results obtained from the application of MESSAGE model, and key conclusions are presented below.

5.1 Primary energy demand

Table 2 shows the primary energy supply mix in 2007 and future years for the three scenarios. It suggests that:

- By 2050, the total primary energy needs of Thailand under the BAU scenario are likely to increase by approximately 4 times the primary energy levels in the year 2007 (Table 4).
- Fossil fuels would continue to dominate the country's primary energy supply mix, accounting for more than 80% of the total primary energy needs under all scenarios.
- Among the fossil fuels, the shares of lignite and coal in total primary energy demand are likely to increase while the shares of crude oil and gas are likely to remain at the current levels.
- For the non-fossil fuel energy, the shares of N&R (*i.e.*, biomass), and other renewables (hydro, geothermal, solar and wind) are estimated to decrease under three scenarios. By 2050, the demand for N&R and other renewables would account for about 4, 5, and 8.5% of the total primary energy needs in the BAU, NP and RE scenarios, respectively.

Table 4. Primary energy requirements (Mtoe).

	BAU				NP			RE		
	2007	2010	2030	2050	2010	2030	2050	2010	2030	2050
Coal	13.7	20.9	41.2	91.7	19.7	37.5	64.9	17.4	36.2	65.9
Oil	50.7	87.5	117.7	197	87.5	121	193.8	68.4	73.7	9.9
Gas	31.3	34.4	54.6	126.4	34.4	48.5	79.1	34.4	48.2	76
Others[a]	1.3	1.1	1.2	0.4	1.1	1.2	0.4	1.2	1.2	0.5
N&R[b]	11.7	11.9	14.5	17.7	11.9	14.5	17.7	12.2	16.4	22.1
Uranium[c]	-	-	-	-	-	3.2	6.2	-	-	-
Total	108.8	155.8	229.2	430.2	154.6	225.9	362.1	133.6	175.7	174.4

[a]Others include hydro, solar, wind, and geothermal
[b]New and Renewable energy (non-commercial)
[c]Uranium import

BAU: Business-As-Usual Scenario
NP: Nuclear Power Scenario
RE: Renewable Energy Scenario

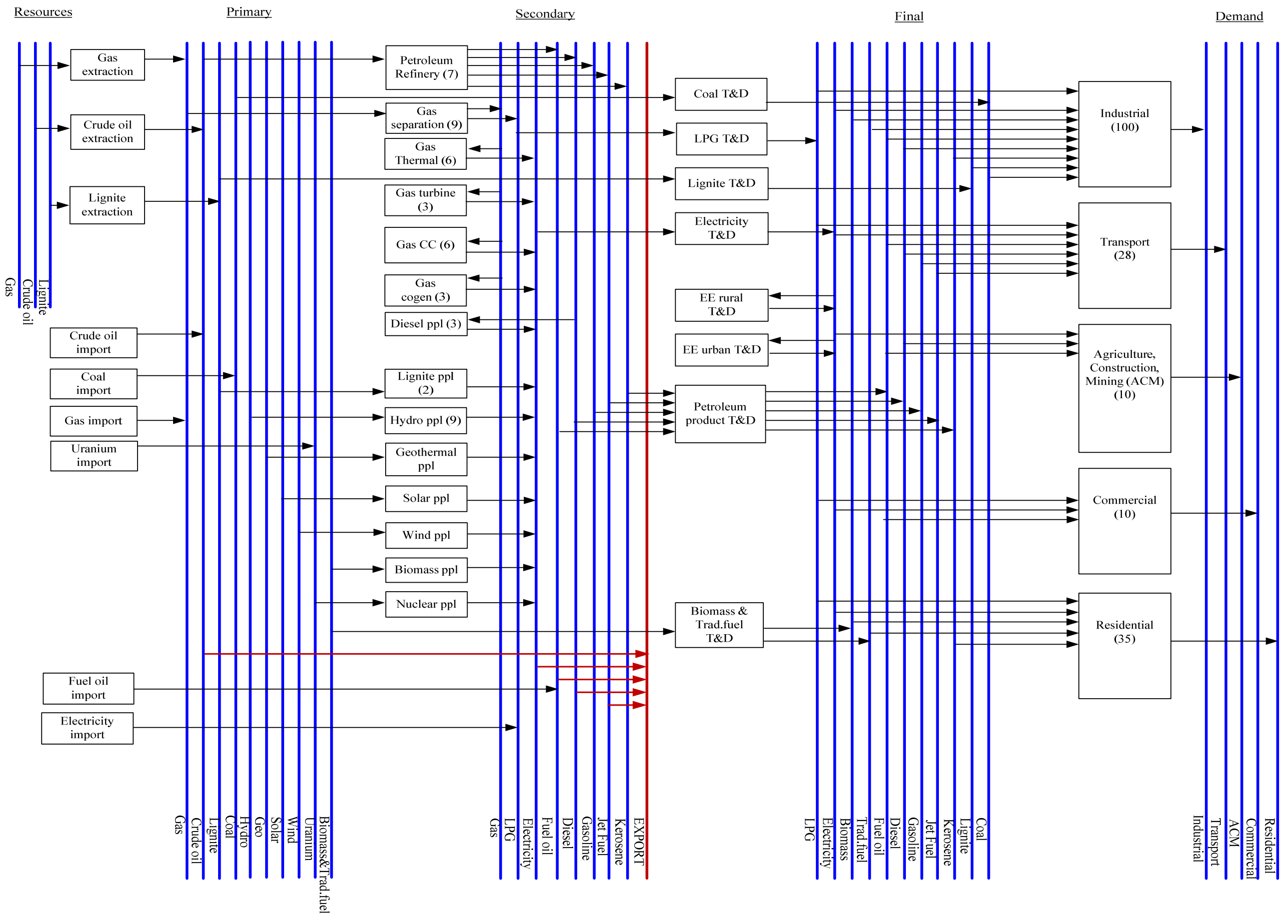

Fig. 2. Thailand's reference energy system.

5.2 *Electricity*

Figure 3 shows the electricity generation capacity mix under the BAU scenario. The highlights include:

- In the BAU scenario, Thailand's power generation capacity is projected to increase annually by 3%, from 141 TWh in 2007 to 371 TWh in 2050. The generation capacity in the NP and RE scenarios are estimated to increase to 385 and 372 TWh respectively.
- In terms of fuel types, in the BAU scenario, gas is likely to maintain its dominant share in electricity generation mix, accounting for nearly 73% of the total generation in 2050. This is followed by coal and lignite (11%), imports (5%), and diesel (2%). The share of other renewable energy (*i.e.* hydro) is expected to decrease to 1% in 2050, while the share of N&R energy (*i.e.* biomass) is likely to increase to 7% by 2050.
- In terms of power generation, in the BAU scenario, coal and gas generations is estimated to provide 84% of total electricity generation in 2050. The remaining (16%) generation is expected to come from other renewables (2%), N&R plants (8%) and imports (6%), respectively.
- In the NP scenario, the introduction of nuclear power appears to significantly affect the electricity generation mix, with nuclear accounting for 15%, coal and gas generations (67%), diesel (2.7%), N&R sources (13%), imports (3%), and other renewables (1%), respectively.

- In the RE scenario, the share of N&R and other resources in total electricity generation is estimated to increase from 8% in 2007, to 65% in 2050. This results in a decreased share of coal and gas generations (28%), imports (3%), diesel (2%) and other renewables (1%).

5.3 Final energy requirements

Figure 4 presents the trends in the final energy requirements under the three alternative policy scenarios. The key findings include:

- Final energy consumption grows annually at 2.9% in the BAU and NP scenarios and 2.7% in the RE scenario, respectively. The total final energy requirements at the end of the study period (2050) is estimated to decrease by 10.5% in the NP and decrease by 20% in the RE scenario, compared to the BAU scenario.
- By the year 2050, the share of industrial sector in total final energy requirements is estimated to be maintained at about 40% in the BAU and NP scenarios, while this share is estimated to decrease to 35% under the RE scenario.
- The share of transport sector is estimated to decrease from 37% in 2005 to 22% in the BAU and NP scenarios, and 25% in the RE scenario, by 2050.
- On the other hand, the share of residential sector in total final energy requirements by 2050 is estimated to increase under all scenarios ranging from 12 to 13% under the BAU, NP and RE scenarios. Likewise, the share of commercial sector is estimated to more than double, from 6% in 2005 to 15% under the BAU and NP, and 17% under the RE scenario.

5.4 CO_2 emissions

Figure 5 presents the total CO_2 emissions under three scenarios. The key findings include:

- Under the BAU scenario, the three sectors namely, electricity, industry and transport sectors would contribute more than 80% to the total CO_2 emissions in 2050. The decreased share of CO_2 emissions of electricity generation from 40% in 2005 to 35% in 2050 is mainly due to the increased share of gas in total fuels used for generation during the study period.
- Similarly, the decreased share of electricity generation in total CO_2 emissions also occurs in the NP scenario, where it decreases to 30% in 2050. The continuing increase of CO_2 emissions from electricity generation would occur only in the RE scenario, which is estimated to reach 43% in 2050. This is due to the preference given by the model to biomass as compared with, for example, natural gas.
- By 2050, the share of industrial sector to CO_2 emissions would increase from 23% in 2005 to 31% in the BAU and NP scenarios, but decrease to 21% in the RE scenario. The significant decrease in share of CO_2 emissions from industrial sector in the RE scenario is mainly due to the decreased share of coal and its replacement by gas and N&R fuels. The CO_2 emissions share of transport sector would decrease from 29% in 2005 to 18, 17, and 17% in the BAU, NP and RE, respectively.

The decreased share of transport sector is mainly due to the continuation of gas in the transport sector instead of oil.

- In the NP scenario, the emission level is likely to follow the BAU trend to the year 2020 and would start to decrease after the introduction of nuclear plants.
- The RE scenario exemplifies how CO_2 emission reductions can be attained over the period 2010-2030. This is mainly due to decreased primary energy requirements in the RE scenario. The significant increase of the emissions in the later period is mainly due to the high share of N&R in the electricity sector. The CO_2 emission factor of the N&R generation (that is, biomass-based generation) combustion is estimated to be even higher than that of gas and diesel fuels (IPCC 2006).

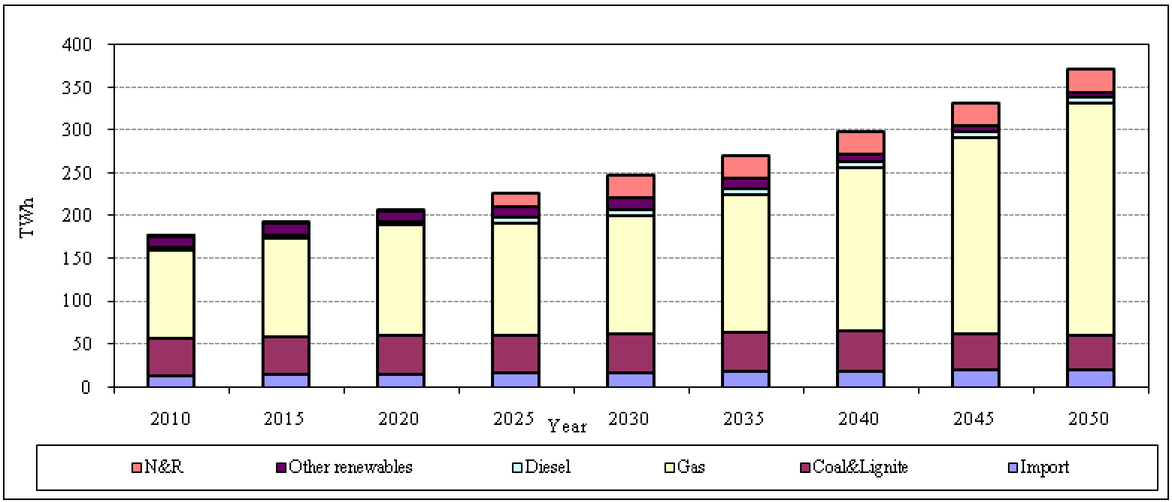

Fig. 3. Electricity generation mix by fuel type (TWh).

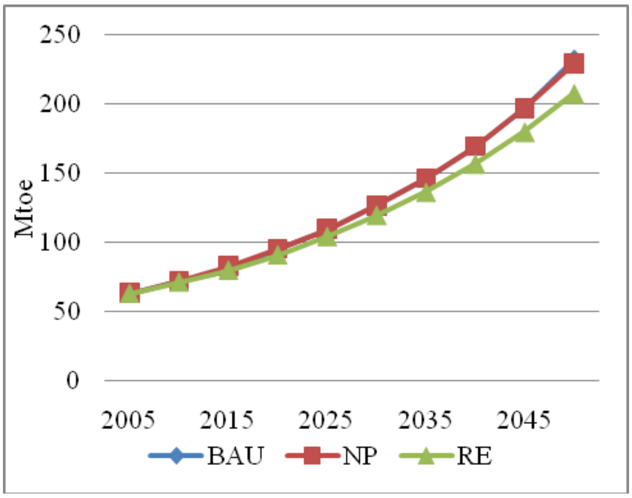

Fig. 4. Final energy requirements under three scenarios.

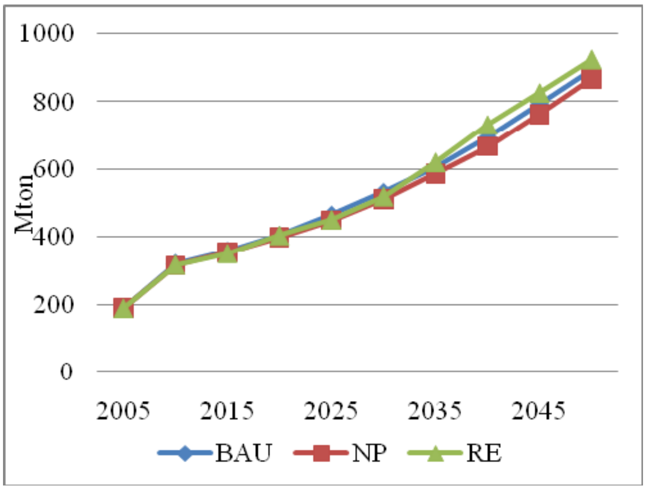

Fig. 5. Total CO_2 emissions under three scenarios.

6. CONCLUSION AND FURTHER DISCUSSION

This paper proposes a comprehensive energy framework for analysing the long-term economy-wide impacts of alternative energy scenarios for Thailand. This framework integrates energy and economy. The energy optimisation is achieved through a Reference Energy System (RES) based MESSAGE model. And, economy-wide impacts are estimated through the application of energy-oriented input-output model. While the main purpose of energy optimisation model is to determine the least-cost technological and resource configuration to meet long-term energy requirements, the energy-economy interaction model aims to investigate the linkage between energy and the rest of economy. The results, based on MESSAGE model, suggest that:

- Under the BAU scenario, Thailand will require 430 Mtoe of primary energy in the year 2050 – this is approximately four times the consumption in 2007. Fossil fuels will continue to be the mainstay of Thailand's energy resource base, accounting approximately for 80% of the total primary energy in all scenarios. The share of coal and lignite in the total primary energy supply mix is expected to increase to 21, 17 and 24% under BAU, NP and RE scenarios, respectively. The share of oil is likely to be 47% in 2007, 45% in BAU, 53% in NP, and 38% in RE scenario. The share of gas is expected to stay at the current level, of approximately 29% under BAU and RE scenarios, and to decrease to 22% in NP scenario. The combined share of N&R and other renewables is likely to decrease from the current 10%, to 4, 5 and 9% under BAU, NP and RE scenarios, respectively. The lower share of renewable energy, despite the Thai government's policy on promoting renewable energy sources, is mainly due to the higher initial costs of renewable technologies and limited resource availability in the country.
- The transport and industrial sectors would continue to be the major energy consuming sectors in the BAU and NP scenarios. These two sectors would consume about 60% of the total final energy consumption in 2050, while the share of residential sector is estimated to increase significantly in the later period of RE scenario. This is mainly due to the fact that no limits or placed on N&R sources in this scenario. This resulted in a significant increase in renewable energy consumed in the residential sector. The energy consumption in the commercial sector is also likely to increase steadily over the study period under the three scenarios.
- In the power sector, the share of gas, coal and lignite combined, in total electricity generation, is estimated to be 84% under the BAU scenario. It will sharply decrease to 67% in the NP scenario, and 28% in the RE scenario, in 2050. The share of N&R and other renewables is expected to be maintained at 7% under the BAU scenario, significantly increase to 13% in the NP scenario, and 65% in the RE scenario. The share of diesel in total electricity generation fuel mix is estimated to be 2% under the BAU scenario, 3% in NP and 2% in the RE scenario. The share of electricity import will account for 5.5% under the BAU scenario, and approximately 3% in NP and RE scenarios.
- Due to the increasing demand for energy in the country, total CO_2 emissions are also estimated to increase in the future in all scenarios. Under the BAU scenario, the total CO_2 emissions are estimated to reach 893 Mt in 2050 – a five-fold increase over the current level. The power generation, industrial and transport sectors will remain as the three major sources of CO_2 emissions in Thailand. The slow increase of CO_2 emissions after the introduction of the nuclear power shows that nuclear is one of the options for the environmental enhancement in the future. The large reduction in CO_2 emissions in the early period of the RE scenario are mainly due to the increased share of gas in electricity generations.

This paper has compared the impacts for BAU, NP and RE scenarios. This comparison has provided useful insights into the energy dynamics of Thailand. The results suggest that the Thai energy sector is still heavily dependent on fossil-fuel, especially natural gas, as a source of energy. The addition of nuclear power is likely to impact the overall energy and electricity system dynamics, as shown in the results of NP scenario. Increased emphasis on renewable technologies, specified in the RE scenario, is likely to provide appreciable environmental gains only at the beginning of the study period. These analyses undertaken in this study provides valuable inputs for the estimation of economy-wide impacts of alternative energy-environmental settings. Further analysis of the economy-wide impacts of three scenarios, employing Input-Output framework, as proposed in this paper, is currently underway.

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REFERENCES

[1] NEPO.1999. Thailand Energy Strategy and Policy, National Energy Policy Office (NEPO), Bangkok, Thailand.

[2] Chaivongvilan, S., Sharma, D. and Sandu, S., 2008. Energy challenges for Thailand: an overview. *GMSARN International Journal* 2: 53-60.

[3] Shrestha, R.M., Malla, S., and Liyanage, M.H., 2007. Scenario-based analyses of energy eystem development and its environmental implications in Thailand. *Energy Policy* 35: 3179-3193.

[4] Patanavanich, S. and D. Phantumvanit. 1991. Global climate change: implications for Thailand's energy systems. *Energy* 16: 1495-1501.

[5] Mulugetta, Y., Mantajit, N., and Jackson, T., 2007. Power sector scenarios for Thailand: an exploratory analysis 2002-2022. *Energy Policy* 35: 3256-3269.

[6] Nakawiro, T., Bhattacharyya, S.C., and Limmeechokchai, B., 2008. Electricity capacity expansion in Thailand: an analysis of gas dependence and fuel import reliance. *Energy* 33: 712-723.

[7] DEDE (several issues) Annual report: Thailand's Energy Situation, Department of Alternative Energy Development and Efficiency, Bangkok, Thailand.

[8] MOE. 2006. About MOE. Ministry of Energy, Royal Thai Government. Accessed from http://www.energy.co.th.

[9] Tiyapun, K., 2008. Thailand's energy demand analysis. Thailand Institute of Nuclear Technology (TINT), Bangkok.

[10] IAEA. 2007. MESSAGE User Manual. International Atomic of Energy Agency, Vienna, Austria.

[11] Wene, C.-O., 1996. Energy-economy analysis: linking the macroeconomic and systems engineering approaches. *Energy* 2: 809-824.

[12] Messner, S., and L. Schrattenholzer, 2000. MESSAGE-MACRO: Linking an energy supply model with a macroeconomic module and solving it iteratively. *Energy* 25: 267-282.

[13] TINT. 2008. Country's Report: Thailand's IAEA/RCA Report in the Context of Climate Change. Office of Atomic for Peace, *IAEA/RCA Final Progress Review Meeting*, December 2008, Bangkok, Thailand.

[14] Greene, D., 2001. Long-term energy scenario models: a review of the literature and recommendations. National Transportation Research Center, Oak Ridge National Laboratory.

[15] O'Toole, R. and A. Matthews. 2002. General equilibrium, partial equilibrium and the partial derivative: elasticities in a CGE model. In *International Conference on Global Modeling (EcoMod 2002)*, 4-6 July, Brussels.

[16] Miller, R.E. and P.D. Blair. 1985. *Input-output Analysis: Foundations and Extensions.* Prentice-Hall, Inc., New Jersey.

[17] Tiwari, P., 2000. An Analysis of Sectoral Energy Intensity in India. *Energy Policy* 28: 771-778.

[18] Pachauri, S. and D. Spreng. 2002. Direct and indirect energy requirements of households in India, *Energy Policy* 30: 511-523.