ASSESSMENT OF ENERGY SECURITY AND CO-BENEFITS OF LOW-CARBON SOCIETY SCENARIOS IN THAILAND

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Abstract

Energy security has become very important in the current energy regime of the world. This paper proposes an assessment framework for measuring energy security named Holistic Energy Security Index (HESI) and then reports a study that used it to measure the energy security of Thailand for the time period of 2007–2030. The HESI is formulated to assess energy security under six main themes which are base diversity, oil security, gas security, vulnerability, sustainability and energy development, and each of these themes has sub-indicators which indicate the level of security in each theme. The Thai energy system has been modeled using an integer programming based optimization model called "Model for Energy Supply Strategy Alternatives and their General Environmental Impacts" (MESSAGE). The energy system has been modeled as an individual case study consisting of 10 scenarios, which include different policy options and measures in the power sector such as Integrated Resource Planning (IRP), Low Carbon Society (LCS) and nuclear power technology. Results indicate that in comparison to the year 2007, the energy security of Thailand has a decreasing trend in the reference scenario. In terms of enhancing energy security, the IRP scenario performs the best followed by LCS and Combined (COM) scenarios. The oil security of Thailand is not increased significantly by the policy options modeled. The gas security is increased by nuclear technology, and by IRP measures. There is significant occurrence of mitigation of local air pollutants such as SO_2 and NOx along with CO_2 mitigation.

Keywords: Co-benefits, energy security, gas security, Low-carbon Society, MESSAGE, oil security, Thailand

Introduction

Energy security has crept into the world geopolitical lexicon with alarming speed, and much time and effort have been dedicated to deciphering what exactly defines the term 'energy security' and its implication to nations in the 21st century (Muller-Kraenner, 2007). Many institutions and organizations involved with energy at a global level have proffered a range of definitions and explanations regarding energy security. The IEA (2007) has defined it

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as the availability of adequate, affordable and reliable supplies of energy. They also go on to add that energy security is very important to economic growth and human development. Energy security is defined by UNDP (2004) as the availability of energy at all times in various forms, in sufficient quantities and at affordable prices, without unacceptable or irreversible impact on the environment. The World Bank Group (2005) states that even though energy security may 'mean different things to different countries, there is a strong common interest in ensuring the world can produce and use energy at reasonable costs and in a sustainable way to ensure the quality of life of the world's peoples'. Another definition given for energy security is 'the ability of an economy to guarantee the availability of energy supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy' (APERC, 2006a). It also goes on to comment that there are several factors which influence the security of supply, including the availability of fuel reserves, the ability of the economy to acquire the energy supplies, level of the economy's ability to meet the projected demand, energy resource diversification and finally the infrastructure to access the energy resources.

Many scientific, peer-reviewed articles have dealt with energy security and the consensus amongst them is that energy security does not have a single, agreed-upon definition (Chester, 2010; von Hippel *et al.*, In Press). In spite of this, the attempt to define and understand the concept of energy security has been rampant. The term 'energy security' is by itself thought to be 'ubiquitous' in contemporary energy issues by Chester (2010). This lends credence to the belief that energy security is an important concept in the energy policy landscape of a country.

Assessing energy security is another sphere that interests policy makers and technologists alike. Kruyt *et al.* (2009) present a critique of already present indicators, dividing them into two main categories, namely simple and composite indicators. Whilst the list is quite comprehensive, many other authors such as Vivoda (2010), Von Hippel, Savage, and Hayes (In Press) have stressed the need for a comprehensive and multi-faceted assessment framework. These works also suggest the incorporation of energy sustainability and energy development into the concept of energy security. Also, in this vein some groundbreaking work has already been done by IEA *et al.* (2004) and IEA (2010). An exhaustive list of energy indicators are presented in the literature mentioned above which helps in determining the sustainability of energy supply and demand in the countries which may use the indicators as a benchmark for the energy sector. Conventional energy security in the early part of 21st century was chiefly measured using oil security and the vulnerability of countries to oil shocks (Vivoda, 2010; Gupta, 2008). Along the same lines, gas security has also been the centre of attention in terms of energy security in Cabalu (2006). Another interesting aspect to be noted is that most of the assessments of energy security and analysis have been carried out for developed countries (Bielecki, 2002; Gnansounou, 2008; Grubb *et al.*, 2006; Le Coq and Paltseva, 2009; Loschel *et al.*, 2010).

In this regard, it can be noted that none of the works that have been covered postulate a comprehensive energy security measuring mechanism for developing countries. Whilst varied aspects of energy security such as diversity, oil security, gas security etc. have been covered, a holistic and comprehensive assessment tool has not been proposed thus far in the literature. This paper intends to fill this research gap by proposing a holistic assessment tool to measure energy security and demonstrates the implementation of this model for Thailand.

A low – carbon society or low-fossil-fuel economy is a concept that refers to an economy which has a minimal output of greenhouse gas (GHG) emissions into the biosphere, but specifically refers to the GHG carbon dioxide (Gomi, *et al.*, 2010). The LCS measures or scenarios that policy makers try to implement are a dire need of the environment as countries are trying their best to counter and mitigate climate change effects (APEC, 2010). Whilst much attention has been given to mitigating carbon emission, the effect carbon emission mitigation action will have on energy security of a country has not been duly documented.

The objective of this research study is to formulate an assessment framework of energy security which encompasses all facets of energy security and to use the assessment framework to measure and analyse energy security and co-benefits of Low Carbon Society scenarios of Thailand.

Methodology

Data Collection

Figure 1 gives the general framework adopted in this research study. The rest of this section gives the succinct description of the individual steps. The socio-economic data and the end-use demand data assumptions have been taken from APERC (2006b) (Table 1). Whilst the demand for 2007 given is secondary data, the growth rate forecast is primary. The information on existing power plants of Thailand and future power plant candidates of Thailand reported in Table 2 and Table 3 respectively have been collected from Power Development Plan (PDP) 2010-2030 (EGAT, 2010) and the data thus presented are secondary in nature. These power plants listed in Table 2 and Table 3 are common to all scenarios which have been modeled for the Thai case study, and hence even though the PDP of Thailand has not been explicitly modeled in the case study, inherently the options are given to the model to choose according to the requirement of minimizing the present value of the total cost of the energy sector. The resource constraints of Thailand and the resource costs have been extracted from Integriertes Ressourcen Management (2008) and Watcharejyothin and

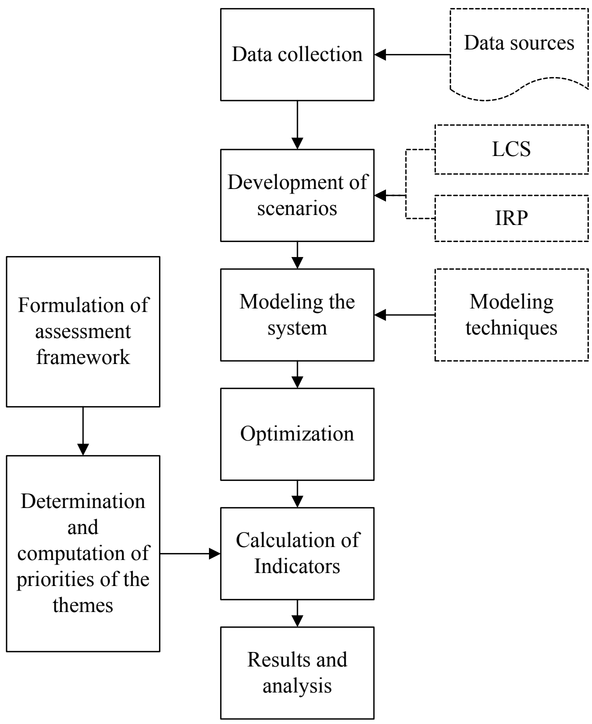

Figure 1. The framework of this study

Shrestha (2009) (Table 4). Most data that have been utilized in modeling the Thai energy sector is secondary data but the data has been collated from published sources or from reports of international developmental organizations. Considering the fact that the results from MESSAGE are dependent on data input care has been given for making sure that the input data are reliable.

Scenario Development and Optimization Using MESSAGE

The Thailand case study has been modeled with 10 scenarios. The descriptions of the scenarios are given in Table 5.

MESSAGE Model

The Thailand case study has been modeled using "Model for Energy Supply Strategy Alternatives and their General Environmental Impacts" (MESSAGE), an integer programming based optimization model (Hainoun *et al.*, 2010). MESSAGE is an energy model which is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates. The model is built to use the principle of optimization of an objective function under a set of user defined constraints. The value of the objective function helps to choose the solution considered the best according to the criteria specified. MESSAGE is a licensed freeware model disseminated by International Atomic Energy Agency (IAEA) for academic and research purposes. The main reason for choosing this software is that the

Table 1. Data assumptions of energy end-use sectors of Thailand (APERC, 2006b)

Demand categories	Demand - 2007 (ktoe)	Growth rate per annum (2007 – 2030)
Electricity	11453.32	
Industry	5260.45	4.5%
Households	2411.53	3.0%
Commercial	3686.48	4.0%
Others	94.86	3.0%
Oil	32318.00	
Industry	6691.00	4.0%
Households	1435.00	1.7%
Commercial	770.00	3.0%
Transport	23422.00	4.4%
Natural Gas	2594.00	
Industry	2386.00	7.3%
Transport	208.00	10.0%
Biomass	11645.00	
Industry	5936.00	4.1%
Households	5709.00	-0.1%
Lignite	1000.00	
Industry	1000.00	5.3%
Coal	5981.00	
Industry	5981.00	5.3%

capabilities of this model match with the general objective of determining the supply side options in the energy sector of Thailand. As the unabridged name of the model suggests, MESSAGE is primarily a model to evaluate supply side strategy alternatives and hence was chosen as the model the Thai case study. The main drawback in MESSAGE is that it is a single objective optimization model and hence its focus is on minimizing the total present value cost of the energy system. All the other modeller required details are given in as constraints but not as the objective.

The case study has been modeled for the time horizon from 2007 to 2030, with the base year being 2007. The emission factors of the power sector have been obtained from IPCC (2007). The Demand Side Management (DSM) options which are modeled in the IRP scenario have been extracted from (du Pont *et al.,* 2008; Foran *et al*., 2010).

Holistic Energy Security Index – HESI

The assessment framework formulated by the authors is named Holistic Energy Security Index – HESI. It encompasses 6 major themes which contribute to assessing energy security of a country. Those 6 themes are Base Diversity, Oil Security, Gas Security, Vulnerability, Sustainability and Energy Development. Each of the 6 themes in turn has sub-indicators which are used to assess each theme, which makes the HESI a composite index. Figure 2 gives the schematic diagram of the proposed HESI.

Base Diversity

The base diversity is the theme which measures the diversity present in the total energy sector of a country and it consists of three sub-indicators which are the Diversification of Primary Energy Demand (DoPED), Net

Table 2. Data of current electricity generation options of Thailand (EGAT, 2010)

Existing power plants	Capacity (MW)	Fixed cost (USD/kW/yr)	Variable cost (USD/MWh)	Availability	Efficiency	Life time (years)
Combined Cycle - NG	12238	23	1.4	0.92	0.42	30
Combined Cycle - Oil						
GT - NG	237	9	0.07	0.96	0.29	30
GT - Oil	610	7	0.29	0.96	0.30	30
Oil- PP	29	21.7	1.44	0.85	0.33	30
Major Hydro	3475	25	0.13	0.45	NA	50
Thermal-Oil	340	22	0.58	0.92	0.34	30
Thermal- NG	5210	21.7	1.44	0.92	0.34	30
Thermal-lignite	2400	21.5	4.7	0.92	0.36	30
Thermal-coal	1347	34.6	0.72	0.92	0.34	30
Cogeneration Oil	94	-	-	-	0.32	30
Cogeneration NG	678	30	0.98	0.4	0.30	30
Cogeneration Biomass	1610	30	3.54	0.75	0.19	30
Cogeneration Coal	17	40	1.63	0.4	0.30	30

Energy Import Dependency (NEID) and Non-Carbon Fuel Portfolio (NCFP). These sub-indicators have been adopted from APERC (2006a). All three sub-indicators are calculated as percentages, where 0 indicates the lowest security and 100 indicates the highest.

Table 3. Data of future power plant options of Thailand (EGAT, 2010)

Future power plants	Capacity (MW)	Investment cost (USD/KW)	Fixed cost (USD/KW/yr)	Variable cost (USD/MWh)	Efficiency
NG - CC 1	670	730	23	1.63	0.5
NG - CC 2	4800	730	23	1.63	0.5
Hydro PS	500	1200	25	1.03	NA
IGCC Coal	800	1550	29	4.68	0.48
IGCC Coal - CCS	800	2082	29	59.35	0.42
Nuclear PP	3000	2510	80	14.4	0.35
Coal Thermal 1	660	1050	38	0.76	0.38
Coal Thermal 2	540	1050	38	0.76	0.38
Power purchase Laos	3650	NA	NA	598 (USD/toe)	1
Power purchase Myanmar	369	NA	NA	598 (USD/toe)	1
Renewable					
Solar PV	5000	4160	9	1.32	NA
Wind Energy	1600	1320	13.5	0.88	NA
Small Hydro	700	2740	49.5	0.13	NA
Biomass Cogeneration	4400	1100	30	3.54	0.3
Biogas Cogeneration	190	1100	30	3.54	0.3
MSW	400	2000	43	5.25	0.29

Table 4. The resource constraints of Thailand (IRM, 2008; Watcherajyothin and Shrestha, 2009)

Resource	Resource cost (USD/toe)	Resource availability (ktoe)
Lignite	71.64	753200.00
Crude Oil	56.17	168000.00
Natural Gas	112.36	275000.00
Biomass	92.05	31751.00
Biogas	-	1087.03
MSW	-	3545.61
Crude Oil - import	368.20	-
Coal - import	92.05	-
Natural Gas - import	288.70	-
Electricity - import	597.67	-

Oil Security

The oil security theme measures the security levels in a country in relation to oil supply and oil dependency and consists of five sub-indicators which are Oil Supply Risk Indicator (OSRI), Oil Import Intensity (OII), Oil Intensity (OI), Oil Share (OS) and Net Oil Import Dependency (NOID). These sub-indicators have been adopted from APERC (2006a) and Gupta (2008). The sub-indicators OSRI, OS and NOID are naturally calculated to be percentages, but OI and OII are obtained as raw values. These values are then normalized according to the method prescribed by Cabalu (2006).

Table 5. The descriptions of the scenarios modeled in the Thailand case study

Name of scenario	Description of scenario
Reference	Reference scenario is where the energy system is modeled for the year 2007 from existing data and the model is allowed to select the technologies and the fuels to fulfill the final end demands according to the least cost criteria. Apart from the restrictions which are common to all scenarios and no external constraints are placed in this scenario.
Status Quo	Status Quo is the scenario where the same trend which exists in the year 2007 will continue throughout the planning horizon. Hence it includes some special constraints, which mirror the selection of the year 2007.
Nuclear - NUC	In Nuclear scenario, the nuclear power plant option is introduced into the planning horizon. Thailand which is planning to introduce nuclear power plants in its generation mix is modeled with the nuclear power option in this scenario.
Integrated Resource Planning -IRP	IRP scenario includes, in addition to the technologies present in the Reference scenario, DSM technologies which are modeled as supply side options in electricity generation in the scenario.
Low Carbon Society 1 - LCS1	LCS1 scenario is the scenario where the constraint of the CO_2 emissions from the power sector is introduced. The constraint limits the total CO_2 emissions from the power sector to be 10% less than the emissions in the Reference scenario. In addition to this another additional feature of the LCS1 scenario is the introduction of clean coal power generation technologies in the power sector of the scenario.
Low Carbon Society 2 - LCS2	Like the LCS1 scenario, LCS2 is the scenario where the CO_2 emission from the power sector is restricted to be 20% less than emissions from the Reference scenario.
Low Carbon Society 3 - LCS3	Like the LCS1 scenario, LCS3 is the scenario where the CO_2 emission from the power sector is restricted to be 30% less than emissions from the Reference scenario.
Combined1-COM1	COM1 scenario is the combination of the constraints of the scenarios LCS1, IRP and NUC.
Combined2-COM2	Likewise, COM2 scenario is the combination of the constraints of the scenarios LCS2, IRP and NUC.
Combined1-COM3	COM3 scenario is the combination of the constraints of the scenarios LCS3, IRP and NUC.

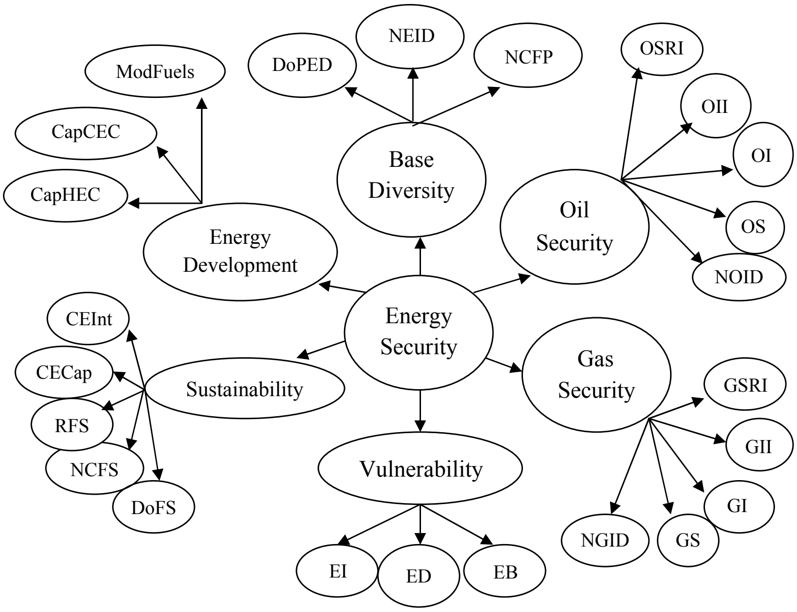

Figure 2. The schematic diagram of HESI

Gas Security

The gas security theme measures the security levels in a country in relation to gas supply and dependency of the energy sector of the said country. Its sub-indicators follow the oil security sub-indicators closely and they are Gas Supply Risk Indicator (GSRI), Gas Import Intensity (GII), Gas Intensity (GI), Gas Share (GS) and Net Gas Import Dependency (NGID). These sub-indicators have been adopted from Cabalu (2006).

Vulnerability

The vulnerability theme measures the vulnerability of a country to energy price shocks or short supply of energy resources and it consists of three sub-indicators which are Energy Intensity (EI), Electricity Diversity (ED) and Energy Bill (EB). These sub-indicators have been adopted from Gnansounou (2008) and Percebois (2007). Again the normalized values of the sub-indicators are given on a scale of 0-100, where 0 denotes the lowest energy security and 100 denotes the highest security.

Sustainability

The sustainability theme measures the sustainability of the energy sector in the long run and consists of five sub-indicators which are Diversity of Fuel Shares (DoFS), Non-Carbon Fuel Shares (NCFS), Renewable Fuel Shares (RFS), Carbon Emission Intensity (CEInt) and Carbon Emission per capita (CECap). These sub-indicators have been adopted from IEA *et al.* (2004).

Energy Development

The theme of energy development measures the energy infrastructure present in a country and consists of three sub-indicators which are Household Energy Consumption per capita (CapHEC), Commercial Energy Consumption per capita (CapCEC) and Share of Modern Fuels in Household sector (Modfuels). These sub-indicators have been adopted from IEA (2010). The equations pertaining to sub-indicators mentioned in sub-sections 2.3.1 to 2.3.6 are presented in Table 6.

Table 6. The equations of the sub-indicators of HESI

Dimension	Indicator	Equation	Reference
Base Diversity	DoPED	$DoPED = \frac{D}{D_{max}}$ where $D = \sum p_i \ln p_i$ And $D_{max} = \ln T$ where, p_i = share of PES i in TPES, D = Shannon's Diversity Index i = number of primary supply options.	APERC (2006a)
	NEID	$NEID = 1 - \frac{DoPED_{importreflective}}{DoPED}$ where $DoPED_{importreflective} = \frac{D}{D_{max}}$ and $D = \sum c_i\ p_i \ln p_i$ subject to c_i = correction factor Where C_i = domestic supply share of resource i	
	NCFP	$\text{NCFP} = \frac{\text{(Hydro PES) + (NRE PES)}}{\text{Total PES}}$	
Oil Security	OSRI	$\text{OSRI} = \frac{\text{Domestic Oil Reserves}}{\text{Oil Consumption}}$	APERC (2006a) and Gupta (2008)
	OII	$\text{OII} = \frac{\text{Cost of Oil Imports}}{\text{GDP}}$	
	OI	$\text{OI} = \frac{\text{Oil Cosumption (toe)}}{\text{GDP (US\$)}}$	
	OS	$\text{OS} = \frac{\text{Primary Oil Cosumption}}{\text{Total Primary Energy}}$	
	NOID	$\text{NOID} = \frac{\text{Net Oil Import}}{\text{Total Primary Energy}}$	
Gas Security	GSRI	$\text{GSRI} = \frac{\text{Domestic Gas Reserves}}{\text{Gas Consumption}}$	Cabalu (2006)
	GII	$\text{GII} = \frac{\text{Cost of Gas Imports}}{\text{GDP}}$	
	GI	$\text{GI} = \frac{\text{Gas Consumption (toe)}}{\text{GDP (US\$)}}$	
	GS	$\text{GS} = \frac{\text{Primary Gas Consumption}}{\text{Total Primary Energy}}$	
	NGID	$\text{NGID} = \frac{\text{Net Gas Import}}{\text{Total Primary Energy}}$	
Vulnerability	EI	$\text{EI} = \frac{\text{Primary Energy Consumption}}{\text{GDP}}$	Ganansounou (2008) and Percebois (2007)
	ED	Shannon-diversity index is used to measure electricity diversity.	
	EB	$\text{EB} = \frac{\text{Cost of Net Energy Imports}}{\text{GDP}}$	

Table 6. The equations of the sub-indicators of HESI (continue)

Dimension	Indicator	Equation	Reference
Sustainability	DoFS	Equation used for DoPED (Shannon Diversity Index) is used in four categories, namely, Primary Energy, Electricity generation mix, Final Energy, and Installed Capacity.	IEA *et. al.* (2004)
	NCFS	Similar **NCFP**, but in four categories Primary Energy, Electricity generation mix, Final Energy, and Installed Capacity.	
	RFS	Similar to **NCFS** but does not include Major Hydro System.	
	CEInt	CO_2 emission intensity $= \frac{CO_2 \text{ emission}}{\text{GDP}}$	
	CECap	CO_2 emission per capita $= \frac{CO_2 \text{ emission}}{\text{Population}}$	
Energy Development	CapHEC	$\text{CapHEC} = \frac{\text{Household Electricity Consumption}}{\text{Population}}$	IEA (2010)
	CapCEC	$\text{CapCEC} = \frac{\text{Commercial Electricity Consumption}}{\text{Population}}$	
	Modfuels	$\text{Modfuels} = \frac{\text{Modern Fuels in Household Sector}}{\text{Total Energy usage in Household Sector}}$	

Incorporation of Analytic Hierarchy Process (AHP)

Whilst it has been noted that the six themes make up HESI, it is not possible to surmise that all the six themes are of equal importance to determining the energy security of Thailand. In reality, the priority of each theme and in turn the priority of each sub-indicator within each theme to assessing energy security varies. In this regard, the authors propose using a decision making tool known as Analytic Hierarchy Process (AHP) (Saaty, 1990) in comparing each theme and each sub-indicator within each theme to determine their relative importance to the HESI of Thailand. The method used is the pair-wise comparisons of the themes and sub-indicators using the Saaty Rating Scale (Saaty, 1990; 2003). The final priorities computed according to expert views and analyses are given in Table 7. From this Table it can be seen that oil security and gas security hold the highest priority in terms of determining the energy security of Thailand.

Results

Results are presented for the HESI of Thailand and then in turn the results achieved for oil security and gas security are revealed. Results of total costs of the energy system modeled for the 10 scenarios were analysed. Then the co-benefits associated with the scenarios were analysed in terms of SO_2 and NOx emissions.

HESI results

Table 8 gives the HESI results of Thailand. It can be seen that the Status Quo scenario has the lowest levels of energy security which implies that continuing along the same technology options in terms of power plants and fuels used in the energy sector causes considerable insecurity in Thailand. In terms of HESI, in the rest of the scenarios, the overwhelming trend that can be observed is that energy security is at moderately high levels in the first two modeled years, namely 2007 and 2010, but progressively decreases regardless of the policy options modeled in the scenarios. The level of decrement varies, yet the underlying trend is the same. In the short to medium term timeframe, energy security of Thailand responds to policy mechanisms which implement IRP and LCS measures but in the longer term (after 2020) continuing with the same policies and the technologies, the respective policies implemented do not increase energy security. One reason for this might be that this research study has not considered any radical changes to the Thai energy sector such as introduction of hydrogen fuel or modal changes in certain sub-sectors like industry or transport. This implies that Thailand needs to consider more mechanisms to enhance its energy security in the longer term.

Table 7. The final priorities of the sub-indicators for Thailand

Theme	Final weights	Theme	Final weights	Theme	Final weights
Base Security	6.00	Oil Security	28.00	Gas Security	28.00
DoPED	2.40	OSRI	3.64	GSRI	4.20
NEID	2.40	OII	6.16	GII	4.76
NCFP	1.20	OI	5.32	GI	5.04
		OS	4.20	GS	2.80
		NOID	8.68	NGID	11.20
Vulnerability	15.00	Sustainability	17.00	Energy Development	6.00
EI	3.45	DoFS	1.19	CapHEC	2.40
ED	1.80	NCFS	4.59	CapCEC	1.20
EB	9.75	RFS	7.14	Modfuels	2.40
		CEInt	2.72		
		CECap	1.36		

Table 8. The Holistic Energy Security Index (HESI) of Thailand for the years from 2007 - 2030

HESI - Thailand										
	Reference	Status Quo	NUC	IRP	LCS1	LCS2	LCS3	COM1	COM2	COM3
2007	68.14	38.65	67.61	68.78	68.63	67.92	67.46	68.58	68.32	67.30
2010	52.25	40.46	51.59	54.35	52.25	54.33	53.85	52.03	52.72	53.06
2015	42.02	40.25	41.33	49.31	41.44	45.17	43.49	42.18	41.25	41.23
2020	40.62	37.90	39.55	44.82	41.06	42.68	41.50	41.11	41.92	39.47
2025	39.37	38.85	39.41	42.37	40.09	40.86	39.39	40.53	40.99	41.42
2030	39.31	39.28	39.15	40.82	40.31	40.90	41.61	39.62	40.88	41.04

In terms of individual analysis of scenarios, IRP scenario performs the best in terms of energy security, followed by the LCS scenarios in the ascending order of LCS1, LCS2 and LCS3 scenarios, and then followed by COM scenarios and finally the reference scenario and NUC scenario. Another interesting aspect to be noted from the results is the trend of HESI values in the individual scenarios for the modeled years. In the case of the IRP scenario, HESI gradually declines from 2007 to 2030, albeit the value higher than the reference scenario. The reason for this is that the energy savings obtained due to DSM measures, which are modeled as a supply side option in MESSAGE, delay the need for coal power plants in Thailand until 2020. But with the demand continuously increasing throughout the time horizon (See Table 1 for the growth rates assumed in the research study), after 2020 the energy savings are not sufficient to cater to the demand and hence there is steady decline in energy security with the introduction of coal power plants. Coal power plants bring down the score of sustainability dimension of HESI in the case of Thailand which results in the decrement in energy security. Whilst experts might argue about the wisdom of the model choosing coal power plants to generate electricity, which might be deemed counter intuitive as IRP is normally associated with DSM and renewable technologies, the model chosen to optimize is a single objective optimization model where the objective function is the total cost. According to the input data, coal power plants are still the cheapest generation options and so the model chooses coal power plants in the IRP scenario.

In the case of the LCS scenarios (LCS1, LCS2 and LCS3), the lowest HESI is reached in the year 2020, and then the energy security starts to improve again. This is different to the behaviour of HESI in the IRP scenario. The same trend exhibited in LCS scenarios is also seen in the COM3 scenario, whilst COM1 and COM2 scenarios exhibit the trend as the IRP scenario. This behaviour might suggest that in the short to medium term horizon IRP options enhance the energy security of Thailand which reinforces the result observed in the IRP scenario, whilst implementing LCS measures improves the energy security in the longer term. As mentioned before, the underlying reason for this might be that whilst DSM options can delay the need for new coal power plants in the short to medium term horizon, the CO_2 reduction which occurs in the LCS and COM scenarios (reductions of 10%, 20% and 30% from the reference scenario for LCS1 and COM1, LCS2 and COM2 and LCS3 and COM3 respectively, as explained in Table 5) increases the dimension of sustainability, especially in the later years (2025, 2030) where the amount of CO_2 emissions reduced is higher than that in the shorter term. These results show that Thailand should, in the shorter term, actively engage in DSM activities and continue to do so in

Table 9 The Oil Security results of Thailand

Oil Security - Thailand										
	Reference	**Status Quo**	**NUC**	**IRP**	**LCS1**	**LCS2**	**LCS3**	**COM1**	**COM2**	**COM3**
2007	22.39	12.01	22.39	22.39	22.41	22.37	22.36	22.41	22.42	22.42
2010	12.24	11.90	12.28	12.39	12.22	12.16	12.15	12.20	12.17	12.16
2015	10.33	12.66	10.36	10.36	10.30	10.17	10.16	10.26	10.25	10.24
2020	11.44	12.17	11.44	11.46	11.37	11.30	11.31	11.32	11.34	11.27
2025	12.46	12.42	12.47	12.39	12.39	12.33	12.33	12.36	12.36	12.34
2030	12.57	13.18	12.59	13.39	13.47	13.32	13.32	13.14	13.44	13.41

conjunction with cleaner power generation mechanism in the longer term.

Oil Security results

The oil security results given in Table 9 are presented out of a score of 28 as per the AHP calculation. The results thus obtained show that there is no significant impact on the oil security of Thailand in any of the ten scenarios, even though the common trend is that oil security decreases with time which is understandable as oil is increasingly needed in the energy sector in the longer timeframe in industry and transport sectors and this oil has to be imported. These results of oil security suggest that Thailand cannot aim to increase their oil security by focusing on the power sector of their country as the use of oil in the power sector is minimal. Rather, the policy makers should focus on other sectors which extensively use oil, such as transport sector, in order to significantly enhance the oil security of Thailand. Some actions which may be considered beneficial to increasing oil security are switching from oil based fuels to biofuels mixes and NG, and at the same time changing the structure of the transport modal share by implementing policies which improve the condition of public and mass transport.

Table 10. The Gas Security results of Thailand

	Gas Security - Thailand									
	Reference	Status Quo	NUC	IRP	LCS1	LCS2	LCS3	COM1	COM2	COM3
2007	23.45	16.61	23.45	24.64	23.71	22.72	21.80	23.71	23.09	22.38
2010	23.22	16.53	23.22	25.64	22.80	23.70	22.93	22.89	22.73	22.66
2015	16.03	14.07	16.05	22.10	15.29	17.84	16.14	16.07	14.94	14.67
2020	14.47	13.29	13.71	18.35	14.49	15.11	13.71	14.29	14.73	12.59
2025	12.39	12.98	12.37	15.29	13.01	12.98	11.18	12.82	13.13	13.12
2030	11.29	11.68	11.30	12.71	11.47	11.65	11.65	11.21	11.81	11.36

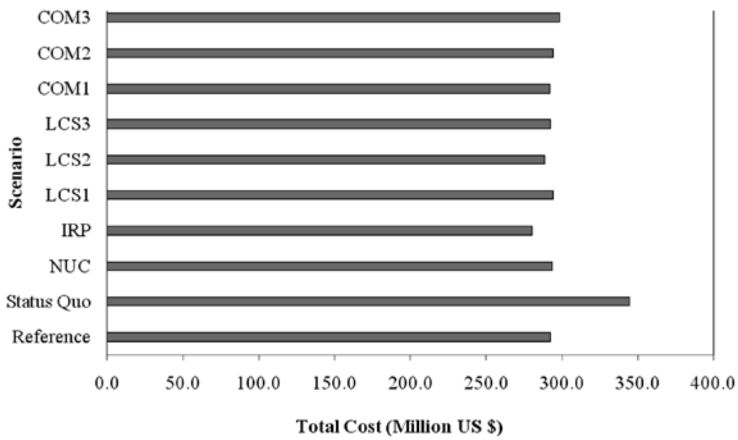

Figure 3. The total cost of the energy sector of Thailand for the varied scenarios

Gas Security results

The gas security values of Thailand, given out of a score of 28 as per the AHP calculations, are given in Table 10. Results presented suggest that even though there is some impact on gas security in the scenarios in comparison to the reference scenario, like oil security for Thailand, gas security also decreases with time. Whilst LCS1 and LCS3 show a decline in gas security, LCS2 shows the second highest improvement in gas security in the modeling period. The results suggest that of the three LCS scenarios, LCS2 is the most optimal scenario for Thailand. Reducing CO_2 emissions by 20% in comparison to the reference scenario is clearly beneficial to improving gas security and even energy security in general. The reason for the decreasing gas security in LCS1 and LCS3 scenarios is due to the avoidance of the use of lignite in the power sector and the increased use of NG in gas power technologies. In the same way, analyzing COM scenarios, the values of gas security are along similar lines to energy security analysed previously. The COM1 scenario shows an improvement in gas security, albeit a very small and insignificant increase, whilst the rest of the COM scenarios show decrement in gas security. Another interesting fact to note is that gas security is slightly reduced in the NUC scenario as well. Despite the presence of the nuclear power options, NG is tipped to play an increasing role in the power sector in the NUC scenario.

Total cost

The total present value costs of each scenario for the time period of 2007–2030 are given in Figure 3. It can be seen that the scenario with the highest total cost is Status Quo scenario. At the same time, it can also be seen that the highest decrease in the total cost is achieved in the IRP scenario because of the cost savings due to DSM measures in the scenario. In terms of the three LCS scenarios, LCS2 which signifies the 20% reduction of CO2 emissions in comparison to the reference scenario has the lowest cost. This implies that out of the 10%, 20% and 30% reduction which are attempted the most optimal one is 20% reduction in the case of Thailand. But this does not hold true in the case of the COM scenarios. In the case of the COM scenarios, the total cost increases in an ascending order from COM1 to COM3.

Analysis of CO_2 emissions

Table 11 gives the results for the emissions of CO_2 from the power sector of Thailand for the individual scenarios. The results show that the lowest CO_2 emissions level is achieved in the LCS3 scenario, which is not surprising as that scenario aims to reduce the emissions by 30% of the emissions level in the reference scenario. Another interesting factor to notice is the marginal improvement in the performance of NUC in terms of the CO_2 emissions. The next analysis will be done by comparing the incremental total cost with the aggregate incremental CO_2 emissions for the scenarios. Without loss of generality, the Status Quo scenario will be disregarded as it performs the worst in terms of both the total cost as well as CO_2 emissions (Figure 4). It can be seen that the best performing scenario in terms of both variables analysed is the LCS2 scenario, where it has the highest decrement in incremental cost as well as the abatement in CO_2 emissions across the total planning horizon. The NUC, LCS1, COM2 and COM3 scenarios all exhibit abatement in terms of CO_2 emissions but have a higher total cost than that of the reference scenario. The LCS2, COM1 and LCS3 scenarios have lower total costs and still provide reduction in CO_2 emissions.

Analysis of SO_2 and NOx emissions

Whilst SO_2 and NOx emissions have not been considered in the formulation of HESI, this research study analyses whether there is any co-benefit in terms of mitigation of SO_2 and NOx. The co-benefits in terms of SO_2 and NOx reduction of Thailand are given in Figure 5 and Figure 6, respectively. The results reported in both the figures distinctly imply a beneficial effect on the reduction of emissions of the gases in the LCS and COM scenarios. But another interesting aspect to be noted here is the spike in the emissions of both the gases in the IRP scenario. This might seem a very counter-intuitive result, especially considering that IRP is generally thought to provide air-pollution reduction as a co-benefit. The reason why this is to the contrary is the power generation options present in the Thai

Table 11. CO_2 emissions of Thailand

CO_2 emissions (kton) - Thailand					
	Reference	**Status Quo**	**NUC**	**IRP**	**LCS1**
2007	70997.47	88557.01	70997.47	76431.80	63900.03
2010	76567.68	88557.01	76567.14	79150.43	68910.02
2015	76360.53	102438.67	76360.53	73130.73	68724.92
2020	112239.22	133760.74	101734.67	113879.20	101015.09
2025	142443.07	148867.32	119867.86	143254.45	128200.06
2030	170166.80	170110.55	147285.18	167863.30	153150.12
CO_2 emissions (kton) - Thailand					
	LCS2	**LCS3**	**COM1**	**COM2**	**COM3**
2007	56799.91	49699.96	63900.03	56800.05	53450.02
2010	61255.07	53600.06	68906.46	61255.03	53600.02
2015	61099.97	53449.96	68724.27	61100.09	53450.05
2020	89800.07	78599.97	93266.85	89719.45	78600.06
2025	114000.06	99999.95	116772.70	113870.12	100000.03
2030	136150.03	119249.91	145531.89	136150.06	119250.09

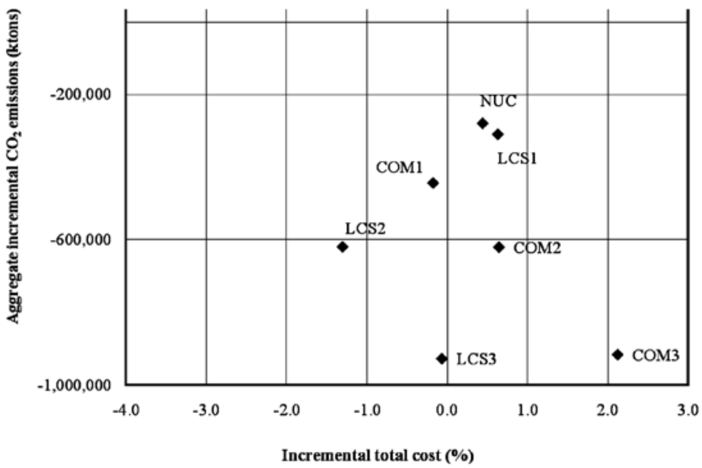

Figure 4. The comparison of incremental total cost and incremental CO_2 emissions in Thailand for the varied scenarios

case study, and the mathematical make-up of the MESSAGE model. In the IRP scenario, regardless of the DSM measures, the MESSAGE model selects the technology which will result in the least cost in terms of total cost of the energy system, and in the case of Thailand the technologies thus selected for the generation of electricity in the IRP scenario are coal and lignite power plants. This is because MESSAGE is a single objective optimization model and hence even after the reduction in the final energy needed to satisfy the demand, the model chooses the generation option with the lowest cost, and this leads to the elevated emissions of NOx and SO_2 emissions. This results in the elevated emission levels of both SO_2 and NOx. Hence, policy makers should be mindful of the co-benefits which accrue to the society when mitigation of CO_2 emissions is considered. As the results suggest, reducing CO_2 emissions will also drastically improve the emission of local air quality in terms of SO_2 and NOx emissions

Conclusions

The energy security of Thailand, as measured by the proposed assessment framework Holistic Energy Security Index–HESI, indicates a downward trend from the year 2007 to 2030 in the reference scenario. The Status Quo scenario which is modeled to

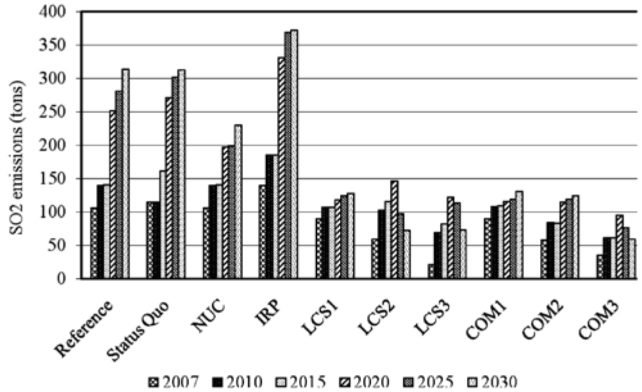

Figure 5. The year-wise SO_2 emissions of Thailand for the varied scenarios

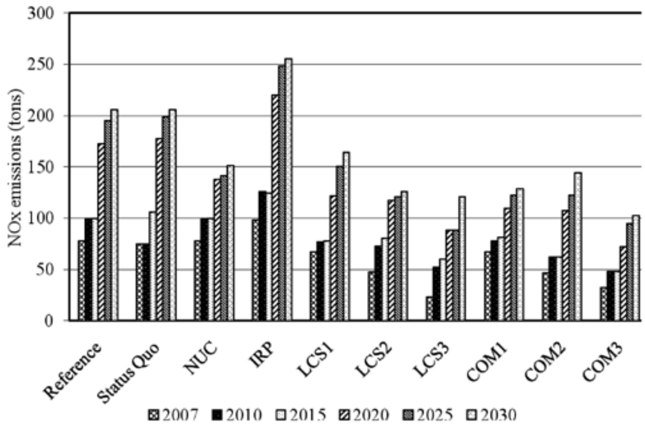

Figure 6. The year-wise NOx emissions of Thailand for the varied scenarios

reflect the actual energy situation of Thailand shows that future energy security declines, which also implies that in the long term the PDP of Thailand should be modified to increase the energy security. The status Quo scenario incurs a higher cost and emits the highest CO_2, along with SO_2 and NOx emissions. The IRP measures undertaken in the power sector improve the energy security of Thailand in the short to medium terms future and CO_2 mitigation measures increase the level of energy security in the long term future. The most beneficial increase in CO_2 mitigation and the cost associated with it are obtained in LCS2 and COM1 scenarios. The oil security is not significantly impacted by the power sector measures modeled in this study, which is understandable as oil is primarily used in the transport sector in Thailand, whilst only a small percentage is used for power generation. On the other hand, gas security is enhanced in the IRP in and NUC scenarios for different reasons; the IRP scenario because of the avoidance of generation of electricity due to demand-side savings, and in the NUC scenario due to nuclear power replacing electricity generation from NG. In terms of co-benefits of energy security and CO_2 mitigation, the LCS and COM scenarios show drastic reduction in both SO_2 and NOx emissions but the IRP scenario, which is based on the least cost concept, has elevated levels of both SO_2 and NOx emissions in comparison to the reference scenario.

Overall, the HESI has the benefits of giving a holistic view on energy security of a country. But one of the main drawbacks of the said tool is that its primary focus has been on the supply side energy security and the reason has been that existing literature and attention have been on energy security through supply side effects. So the model chosen (MESSAGE) is also an energy model which specializes and models supply side strategies. Further research and conceptualization need to go into incorporating demand side and energy services side energy security, and further exploration needs to be undertaken to arrive at an energy model which may model the energy system in terms of demand side sector.

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References

Asia Pacific Economic Cooperation (APEC). (2010). The 2050 Scenarios: Low Carbon-High Quality Lifestyle for the Asia Pacific. APEC Center for Technology Foresight.

Asia Pacific Energy Research Centre (APERC). (2006a). A Quest for Energy Security in the 21st Century - resources and constraints. Tokyo. Available from: http://www.ieej.or.jp/aperc/2007pdf/2007_Reports/APERC_2007_A_Quest_for_Energy_Security.pdf

Asia Pacific Energy Research Centre (APERC). (2006b). APEC Energy Demand and Supply Outlook. Tokyo: Asia Pacific Energy Research Centre. Available from: http://www.ieej.or.jp/aperc/2006pdf/Outlook2006/Whole_Report.pdf

Bielecki, J. (2002). Energy security: is the wolf at the door? The Quarterly Review of Economics and Finance, 42(2):235-250.

Cabalu, H. (2006). Indicators of security of natural gas supply in Asia. Energy Policy, 38(1):218-225.

Chester, L. (2010). Conceptualising energy security and making explicit its polysemic nature. Energy Policy, 38(2):887-895.

Department of Alternative Energy Development and Efficiency (DEDE). (2007). Thailand Energy Situation. Bangkok: DEDE.

du Pont, P., Cherniack, M., Philips, M. and Patanavanich, S. (2008). Thailand's Demand Side Management Initiative: a practical response to global warming. Available from: archive.unu.edu/unupress/unupbooks/80836e/80836E00.htm.

Electricity Generating Authority of Thailand (EGAT). (2010). Summary of Thailand Power Development Plan 2010-2030. Bangkok: Electricity Generating

Authority of Thailand.

Foran, T., du Pont, P., Parinya, P. and Phumaraphand, N. (2010). Securing energy efficiency as a high priority: scenarios for common appliance electricity consumption in Thailand. Energy Efficiency, 3:347-364.

Gnansounou, E. (2008). Assessing the energy vulnerability: Case of industrialised countries. Energy Policy, 36(10):3734-3744.

Gomi, K., Shimada, K. and Matsuoka, Y. (2010). A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. Energy Policy, 38(9):4783-4796.

Grubb, M., Butler, L. and Twomey, P. (2006). Diversity and security in UK electricity generation: The influence of low-carbon objectives. Energy Policy, 34(18):4050-4062.

Gupta, E. (2008). Oil vulnerability index of oil-importing countries. Energy Policy, 36(3):1195-1211.

Hanoun, A., Seif Aldin, M. and Almoustafa, S. (2010). Formulating an optional long-term energy supply strategy for Syria using MESSAGE model. Energy Policy, 38(4):1701-1714.

International Energy Agency (IEA). (2007). World Energy Outlook 2007. Paris: International Energy Agency.

International Energy Agency (IEA). (2010). Energy Poverty-How to make modern energy access universal. Paris: IEA - OECD.

IEA, IAEA, Eurostat, EEA, and UNDESA. (2004). Energy Indicators for Sustainable Development: Guidelines and Methodologies. Vienna: IEA, IAEA, Eurostat.

Integriertes Ressourcen Management (IRM-AG). (2008). Economics of Energy Integration: Application of MESSAGE Model in the GMS. Manila: Asian Development Bank.

IPCC. (2007). Climate Change Mitigation 2007, Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Chnage. Cambridge, UK, New York, USA: IPCC.

Kruyt, B., van Vuuren, D.P., de Vries, H.J.M. and Groenenberg, H. (2009). Indicators for energy security. Energy Policy, 37(6):2166-2181.

LOschel, A., Moslener, U. and Rubbelke, D. T. G. (2010). Indicators of energy security in industrialised countries. Energy Policy, 38(4):1665-1671.

Le Coq, C., and Paltseva, E. (2009). Measuring the security of external energy supply in the European Union. Energy Policy 37(11):4474-4481.

Muller-Kraenner, S. (2007). Energy Security: Re-Measuring the World: Earthscan.

Percebois, J. (2007). Energy vulnerability and its management. International Journal of Energy Sector Management, 1 (1):51-62.

Saaty, R.W. (2003). Decision making in Complex Environments. Pittsburg: SuperDecisions.

Saaty, T.L. (1990). How to make a decision: The analytic hierarchy process. European Journal of Operational Research, 48(1):9-26.

The World Bank Group. (2005). Energy Security Issues. Washington DC: The World Bank Group.

UNDP. (2004). World Energy Assessment: Overview. United Nations.

Vivoda, V. (2010). Evaluating energy security in the Asia-Pacific region: A novel methodological approach. Energy Policy, 38(9):5258-5263.

Von Hippel, D., Savage, T. and Hayes P. Introduction to the Asian Energy Security project: Project organization and methodologies. Energy Policy, In Press, Corrected Proof.

Von Hippel, D., Suzuki, T., Williams, J.H., Savage, T. and Hayes, P. Energy security and sustainability in Northeast Asia. Energy Policy, In Press, Corrected Proof.

Watcharejyothin, M. and Shrestha, (2009). R.M. Regional energy resource development and energy security under CO2 emission constraint in the greater Mekong sub-region countries (GMS). Energy Policy. 37(11):4428-4441.