Assessment of Energy Security of an Energy Import-Dependent Country: a Case Study of Sri Lanka

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Abstract

Energy security is an important aspect of energy policy of most countries; however, there is no consensus on a common definition of energy security. This paper presents an assessment framework of energy security for Sri Lanka, an energy import-dependent country. The assessment framework, named Holistic Energy Security Index, consists of six dimensions of energy security. Each dimension is prioritized using the Analytic Hierarchy Process (AHP) according to characteristics of the case study. The energy security of Sri Lanka for 2007-2030 is assessed using the Holistic Energy Security Index. The policy paths consisting of integrated resource planning (IRP) and low carbon society (LCS) measures, and their impacts on energy security of Sri Lanka, are assessed. The results from the Model for Energy Supply Strategy Alternatives and Their General Environmental Impacts (MESSAGE) show that both IRP and LCS measures have positive impacts on energy security of Sri Lanka, when compared for the current the energy policy of Sri Lanka. Results also show preference for LCS measures, which have a higher positive impact on energy security. The total levelized cost of the energy system is lower in both IRP and LCS scenarios, in comparison to the base case.

Keywords: Energy Security, MESSAGE, Analytic Hierarchy Planning (AHP), Integrated Resource Planning (IRP), Low Carbon Society (LCS)

1. Introduction

Energy is one of the most important latent commodities which have high nation-wide impacts. A simple theory of economics dictates that resources are not spread throughout the world in equal measure [1]. This creates an imbalance in terms of energy resources as well. While some countries possess a considerable amount of energy resources, some have to depend on imports of these energy resources to go about their business. This factor coupled with non-renewability of conventional energy resources such as crude oil and natural gas have brought about the need for nations to be energy secure.

Much attention has begun to be given to energy security in general, but a universally accepted definition does not exist as yet [2]. Many research and policy-making institutions have conducted research for developed countries in Europe and America detailing their supply side securities [3-9], but there is a gap in research study in terms of import-dependent developing countries. Though many international organizations have done research on the energy sector of developing countries, they have all been on the effects of analyzing the role energy plays in development [10-15].

A considerable amount of work in terms of the energy sector's policy has been accomplished for Sri Lanka [16-18], but none has been explicitly focused on energy security. Though the present government of Sri Lanka has energy security as one of its objectives [19], there is a gap in research study to achieve it or even what energy security implies in the context of Sri Lanka.

In this regard, the objective of this study is to formulate an energy security index for an import-dependent developing country like Sri Lanka and analyze and assess the levels of energy security in the future for different energy scenarios.

The next section in extension gives the background of the Sri Lankan's energy sector, followed by a literature review of energy security and the methods of analysis. The subsequent sections are the methodology, results and discussion, and the conclusions.

2. Sri Lanka and Energy System

2.1 Sri Lanka's Energy sector

The Sri Lankan energy sector in 2007 is primarily a biomass-based energy system with the traditional use of biomass in rural households dominating the energy mix [20]. Electricity accounted for 8% of the final energy mix which is low when compared to other developing countries. but moderate in comparison to other countries in the region. Sri Lanka's power sector is dominated by oil fired thermal generation [21] which places a burden on the economy due to imported oil. Oil is also used for transportation. However, Sri Lanka lacks conventional non-renewable energy resources.

2.2 Energy Security

Energy security, even though described to be ubiquitous [2] does not have a universally accepted definition. The European Commission and the International Energy Agency (IEA) define energy security as the provision of reasonably priced, reliable and environmentally friendly energy [22, 23]. However, [1] argued that the terms used in this definition are lacking details, and the definition of the terms 'reasonably priced', 'reliable', etc. are ambiguous. Energy security is defined as the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economy [24]. Energy security is also discussed along the lines of three aspects, which are physical energy security, economic energy security, and environmental sustainability. It can be safely presumed that energy security has been broadly framed as the uninterrupted availability of energy, and energy insecurity will imply the risk of interruption to energy service. Energy security has been treated in the literature to hold relevance with diversity of energy supply, the method of acquisition of the energy supply, and with its impact on the environment.

2.3 Indicators of Energy Security

Many authors have contributed to creating indicators and indices to measure and evaluate energy security, but they vary in their approaches. Some indicators exclusively look at the security of supply by measuring the diversity of energy supply [4, 25] while others have sought to correlate energy security with that of the availability of oil or natural gas [26, 27]. Also, some of them try to go beyond the market centric [2] definitions offered, rather looking at a holistic indicator [28, 30] to measure energy security. On the other hand, a few indicators have connected energy security and the concept of energy vulnerability, inferring that energy vulnerability means a lack of security. Indices were created to measure vulnerability [31, 32]. One important opinion offered in this aspect is by [2]. The energy security is dependent on the context and means different things to different parties. This is important to note when selecting the appropriate indicators to measure energy security.

Most energy security indicators predominantly look at the security or ease at which most primary energy forms are acquired by a country. They also give importance to how much a country's energy system is dependent on a particular energy source or how diverse the energy system is and whether energy sources are available in the country or whether they have to be imported.

The indicators and measurement methods proposed in the literature were found to measure or assess one main facet of energy security. One of the valid points made by [28, 30] is that given the multiple dimensions of energy security identified by the literature review, the measurement framework of energy security should be able to incorporate sustainability and sustainable development. The energy security indices in the literature are sufficient; however, they are not complete. In this regard the author proposes a more holistic energy security index incorporating multiple dimensions of energy security, which are especially important to import-dependent developing countries.

2.4 Holistic Energy Security Index

The proposed energy security index has six dimensions which are base security [33], oil security [27], gas security [26], vulnerability [32, 34], sustainability [12, 32, 34-37], and energy development [10]. In the case of Sri Lanka's energy system, where natural gas does not play a part, gas security will be omitted, and the indicator will consist of five dimensions. While these dimensions are not completely new ones to the field of energy science, they are indeed novel in terms of incorporating them into the concept of energy security. For example, the dimension of sustainability has been borrowed and incorporated, after the study of its use in energy policy development [12-14, 38-40]. The dimension of energy development has been incorporated because most developing countries lack proper energy infrastructure facilities, which are not an inherent part of energy security, but is still a vital component [10]. The complete list of the sub-indicators for each dimension can be seen in the Appendix.

Another important feature of the proposed energy security index is its adaptability and flexibility subject to the country or region. A prioritizing technique called "Analytic Hierarchy Process" or AHP is employed to give weights to the six dimensions of energy security and the sub-indicators of individual dimensions. The methodology is discussed in detail in the next section.

2.5 MESSAGE Model

The computer model chosen to build the Sri Lankan case study is called the "Model for Energy Supply Strategy Alternatives and Their General Environmental Impacts" or MESSAGE, which is an integer programming based optimization model [41]. A case study has been created to articulate the real system as realistically as possible, keeping in mind the constraints present in the real system [42]. The flow diagram of the MESSAGE model is given in Fig. 1.

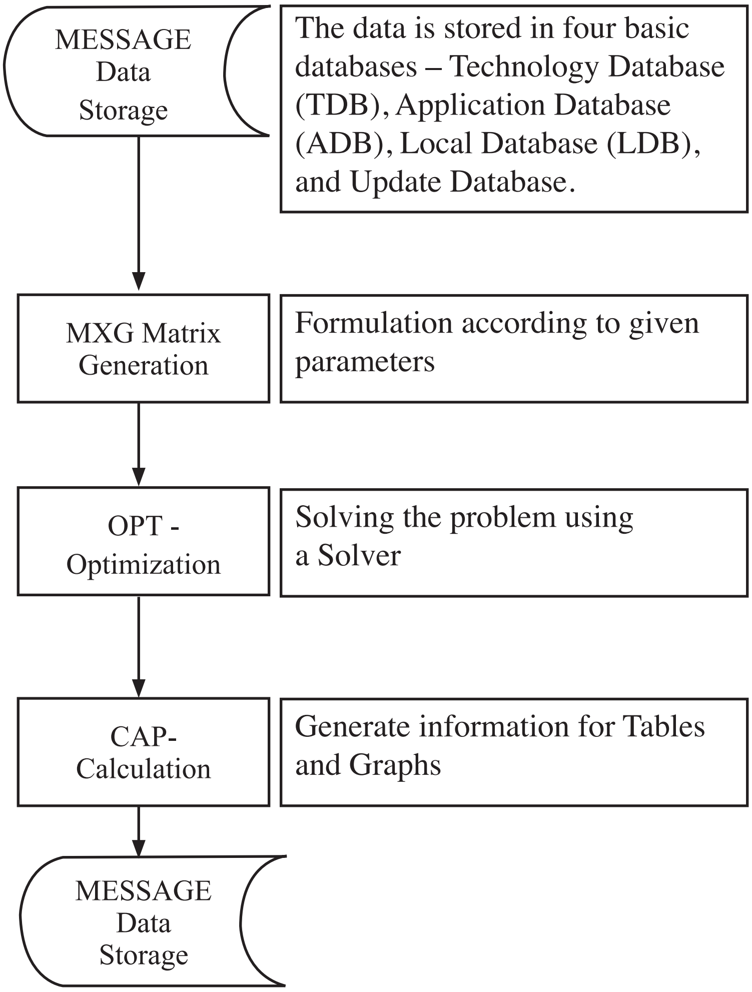

Fig. 1. Flow diagram of the MESSAGE Model.

MESSAGE model consists of four databases, through which the user inserts and stores the necessary data. These databases are namely Technology Database (TDB), Application Database (ADB), Local Database (LDB), and Update Database (UPD). Once the relevant data is inputted then the modeler gives the command to optimize which prompts the model to create the matrix through the Matrix Generation (MXG) option. Subsequent to that, the problem is solved by optimizing and finally the necessary information for presentation of results is done through the CAP (Calculation of Problem) option.

2.6 Integrated Resource Planning (IRP)

Integrated resource planning (IRP) is defined as the combined development of electricity supplies and demand-side management (DSM) options to provide energy services at a minimum cost, including environmental and societal costs [43]. This concept can be understood further from [44].

2.7 Low Carbon Society (LCS)

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 [45]. The society will adopt a lifestyle that makes more use of energy efficient devices and renewable energy technologies. Research studies normally list energy security as a co-benefit of LCS, as LCS inherently advises moving away from fossil fuels [46].

3. METHODOLOGY

3.1 Energy System Modeling and Optimization

The case study of Sri Lanka has been built in the MESSAGE model and altogether eight scenarios have been modeled and the results have been obtained.

The study period is 2007-2030, in which the base year is 2007 due to availability of data.

3.1.1 Scenario Description

The least cost scenario is the scenario upon which other scenarios are built into, to make meaningful comparison in terms of the variation of energy security with policy options. Hence the technological options for power generation are common for the other scenarios as well. The data for power generation options are given in Table 2.

Table 1 The socio-economic assumptions of the research study.

Year	Population	GDP in USD (billion)	Industry sector contribution in USD (billion)	Commercial sector contribution in USD (billion)
2007	20 010 000	32.70	9.32	19.49
2010	20 616 000	37.85	10.79	22.56
2015	21 668 000	48.31	13.77	28.79
2020	22 773 000	61.66	17.57	36.75
2025	23 935 000	78.70	22.43	46.90
2030	25 156 000	100.44	28.63	59.86

Note: The GDP is given in constant US Dollars.

Table 2 Data regarding power generation options in Sri Lanka.

Technology	Investment cost (USD/kW)	Maximum capacity (MW)	Fixed cost (USD/kW/Year)	Variable cost (USD/toe)	Efficiency	Plant life (years)	Unit size (MW)
Oil PP [21]	N/A	1114.5	60	N/A	0.412	N/A	N/A
Hydro1 [21]	N/A	1187	12	0.13	N/A	N/A	N/A
Small Hydro	2500	1000	11	0.13	N/A	50	20
Wind	1100	1000	9	0.88	N/A	30	30
Biomass	1200	1500	21.6	2.5	0.3	25	3
Hydro2 [48]	2218.4	150	12	0.13	N/A	50	150
Hydro3 [48]	2762.3	100	12	0.13	N/A	50	100
Hydro4 [48]	2860.7	49	12	0.13	N/A	50	49
Oil combined cycle	676.5	600	3.9	N/A	0.48	30	300
Coal PP1 [48]	1159.5	900	7.5	2.44	0.375	30	300
Coal PP2	1159.5	1000	7.5	2.44	0.375	30	500

The probable scenario is the most likely scenario to take place, mirroring the past, with certain constraints in place, which show the inertia in implementing certain policy options to achieve least cost objectives. The minimum annual utilization of the oil thermal power plants is set at 50% and the maximum possible capacity addition of biomass power plants is set at 150 MW. They reflect the trends that have already been in place in the Sri Lanka's energy system. Likewise the maximum possible installation in wind and small hydro power plants is 100 and 150 MW annually.

The next of the six scenarios have been designed to accommodate certain prerogatives of policy directions. IRP1 includes demand-side management (DSM) options, and IRP2 includes efficiency improvement in the transmission and distribution of the grid. The LCS1 and LCS2 scenarios place an upper bound on the maximum allowable CO2 emission. They also introduce clean coal technologies in addition to the conventional coal technologies. The C1 and C2 scenarios are the combination of IRP1 and LCS1, and IRP 2 and LCS2, respectively.

3.1.2 Priorities and Weights using AHP

Analytic Hierarchy Process (AHP) is defined as a multi-criteria decision making approach in which factors are arranged in a hierarchic structure [49]. In the research study being conducted here, energy security is formulated as being made up of five dimensions (in the case of Sri Lanka) and each dimension consisting of various sub-indicators. This was defined as the holistic energy security index. An assumption would have to be made that the dimensions are of equal consequence. Priorities and weights were assigned to individual dimensions and sub-indicators by analysis of the literature and experts' views and the end-priorities were computed using the licensed software called "SuperDecisions" [50]. The priority matrix and the weights arrived at the end of calculation are given in Table 3. The index will be on a scale of 0-100 with contributions being from the five dimensions.

Table 3 Priority matrix and the weights of the dimensions of energy security for Sri Lanka.

	Base indicators	**Oil security**	**Vulnerability**	**Sustainability**	**Energy development**	**Weights normalized to 100**
Base indicators	1.00	0.20	0.33	0.25	0.50	6
Oil security	5.00	1.00	3.00	2.00	4.00	42
Vulnerability	3.00	0.33	1.00	0.50	2.00	16
Sustainability	4.00	0.50	2.00	1.00	2.00	25
Energy development	2.00	0.25	0.50	0.50	1.00	11

4. Results and Discussion

4.1 Results of Energy Security

The above table presents the Holistic Energy Security Index for the eight scenarios. Besides the probable scenario, the other seven scenarios show improvement in energy security. The best energy security is achieved in LCS, C1, and C2 scenarios. On a scale of 0 to 100, energy security lingers in a poor state for the period of 2007-2030 in the probable scenario, where-as in the other scenarios it reaches a higher security state. It can also be noticed that The IRP1 and IRP2 scenarios are slightly lower in energy security than the least cost scenario. This is due to two reasons. Those two scenarios with electricity generation from coal power plants is not constrained, hence it implies that coal is imported, which affects the use of indigenous sources (renewable energy technologies). Another reason is that CO2 emission is not constrained, and leads to a lower score on the sustainability dimension of energy security.

The IRP1 and IRP2 scenarios show increasing energy security when compared to the Probable case. The LCS1 and LCS2 scenarios, and the C1 and C2 scenarios also show increasing energy security.

4.2 Total Levelized Cost

In terms of total levelized cost of the energy system it can be noted that the probable scenario will incur the highest cost. The most cost-effective are the C1 and C2 scenarios followed by the IRP1 and IRP2 scenarios, and then finally the LCS1 and LCS2 scenarios.

It is interesting to note that all six policy scenarios are more cost-effective than the least cost scenario. So this implies that the policy options not only improve energy security, but also reduce the total system cost. This is because even though the least cost might suggest that eventually it should incur the lowest levelized cost, the options the other six scenarios have, in reality, made it possible for the MESSAGE model to optimize and obtain a better result in terms of the cost. For example, for the case of IRP because of DSM options, the electricity that needs to be generated is lower and hence the cost of the system throughout the modeled period is reduced. This results in the other policy cases having a lower levelized cost than the least cost scenario as shown in Fig. 2.

Table 4 Holistic Energy Security Index for Sri Lanka.

	Least cost	Probable	IRP1	IRP2	LCS1	LCS2	C1	C2
2007	40.79	28.22	52.16	52.16	50.23	50.23	52.16	52.12
2010	64.50	33.19	63.89	63.45	63.76	63.62	63.45	63.44
2015	64.27	36.81	63.13	62.39	63.03	62.85	62.62	62.38
2020	62.72	40.91	61.33	60.38	61.27	62.75	60.06	60.37
2025	60.30	44.17	58.85	58.96	62.42	62.43	61.20	63.31
2030	62.01	46.99	60.76	59.64	63.70	64.25	62.67	63.28

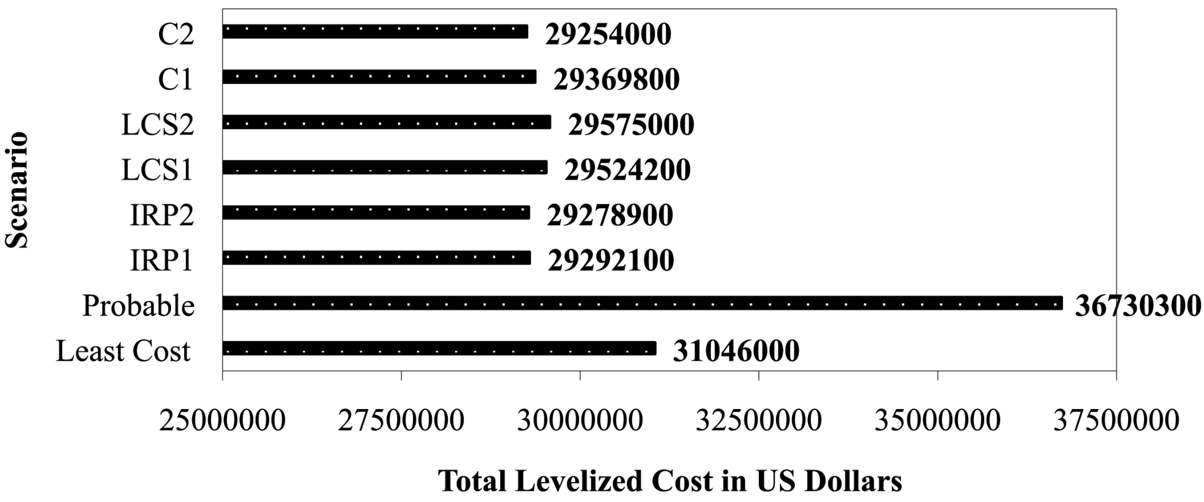

Fig. 2. Total levelized cost of energy system in all scenarios.

4.3 Analysis of Scenarios

Fig. 3 gives the energy security as measured by the proposed index, with their constituent elements for the year 2010. It can be seen that except for the probable scenario whose level of energy security as discussed in the previous section lies in the poor region, all the other scenarios are better. In terms of vulnerability and sustainability dimensions in 2010, the least cost scenario outdoes the other six scenarios with policy options. This is because, the 2010 modeled year has a short time lapse from the previously modeled year which is 2007, where the effects and benefits of policy options such as IRP and LCS are not yet realized. This can be understood by analyzing the results for 2020.

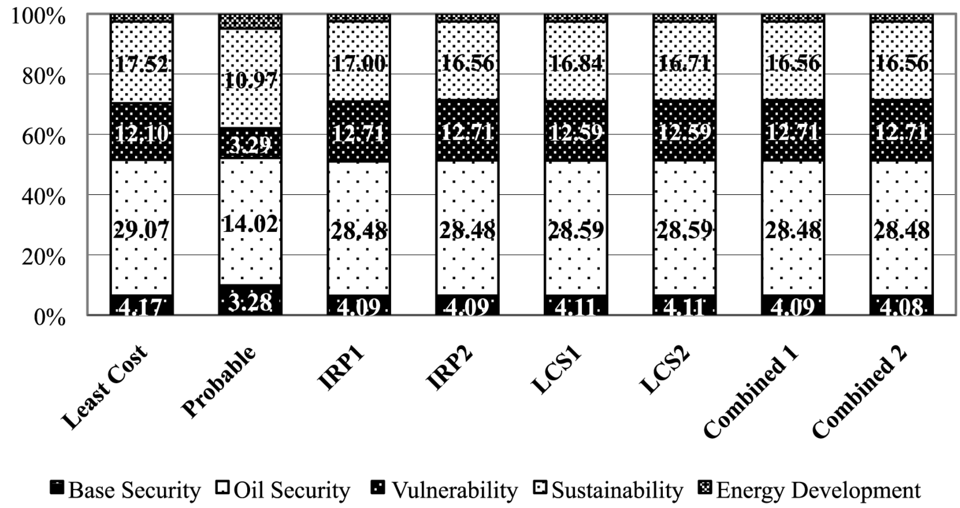

Fig. 3. Energy security in 2010.

In Fig. 4 it can be seen that sustainability and oil security dimensions of IRP1 & IRP2, LCS1 & LCS2, and C1 & C2 scenarios reach almost the same level as the least cost scenario, which implies lower levelized costs.

In Fig. 5 an extension of the same behavior can be observed in all cases. In the oil security dimension, the C1 & C2 scenarios overtake the least cost scenario, which implies that both policy options have a beneficial effect on the energy security of Sri Lanka in the long term.

Another interesting point is that LCS and C1 & C2 scenarios, across all three years, not only show the highest oil security and sustainability, but also show near-perfect scores in the vulnerability dimension. In terms of timeline, they also show reduction in sustainability due to increasing in CO_2 emission from power generation. Results also show that the energy development dimension does not vary significantly across the scenarios. This implies that if one needs to improve energy development, one needs to look at different policy pathways besides the IRP and LCS options.

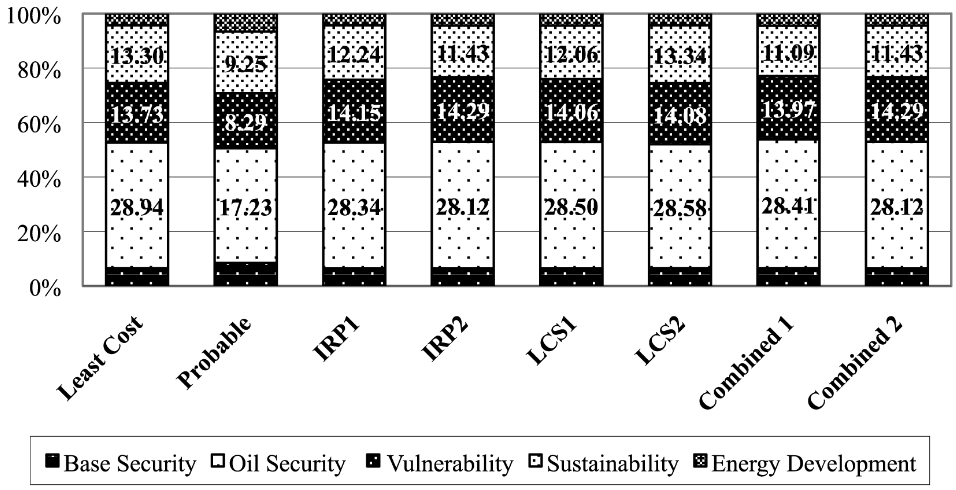

Fig. 4. Energy security in 2020.

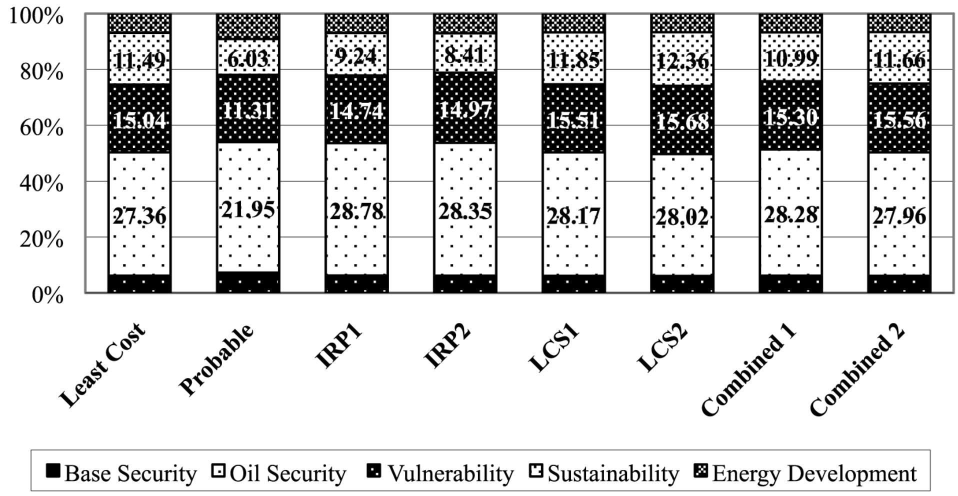

Fig. 5. Energy security in 2030.

5. Conclusion

This paper presented a framework and an index to comprehensively measure energy security of an import dependent developing country. An energy security index is built up consisting of six dimensions. Each dimension consists of sub-indicators through which energy security can be assessed. Then, AHP is used to prioritize the dimensions. Thus, the Holistic Energy Security Index was used to assess the energy system of Sri Lanka. Sri Lanka's energy system was modeled using MESSAGE. Eight scenarios were modeled and six of them on the basis of policy options of IRP and LCS measures. The results obtained by optimization in MESSAGE were used to assess energy security of Sri Lanka.

Results show that the IRP and LCS scenarios have significant impacts on increasing energy security of Sri Lanka. They also show that these measures reduce the total levelized cost of the energy system. The C1 and C2 scenarios also have similar impacts to that of LCS in terms of increasing energy security.

Acknowledgement

The authors would like to thank Sirindhorn International Institute of Technology, Thammasat University (SIIT-TU) and the Joint Graduate School of Energy & Environment (JGSEE), KMUTT for giving the opportunity and financial resources to conduct this research.

6. References

[1] Muller-Kraenner, S., Energy Security: Re-measuring the World, Earthscan, 2007.

[2] Chester, L., Conceptualizing energy security and making explicit its polysemic nature, Energy Policy, Vol. 38, No. 2, pp. 887 - 895, 2010.

[3] Grubb, M., Butler, L., and Twomey, P., Diversity and security in UK electricity generation: The influence of low-carbon objectives, Energy Policy, Vol. 34, No. 18, pp. 4050 - 4062, 2006.

[4] Jansen J. C., van Arkel, W. G., Boots, M. G., Designing indicators of long-term energy supply security, Environment Assessment Agency, Netherlands, 2004.

[5] Jansen J. C., and Seebregts, A. J., Long-term energy services security: What is it and how can it be measured and valued? Energy Policy, Vol. 38, No. 4, pp. 1654 - 1664, 2010.

[6] Kruyt, B. et. al., Indicators for energy security, Energy Policy, Vol. 37, No. 6, pp. 2166 - 2181, 2009.

[7] Loschel, A., Moslener, U., and Robbelke, D. T. G., Indicators of energy security in industrialized countries, Energy Policy, Vol. 38, No. 4, pp. 1665 - 1671, 2010.

[8] Salameh M. G., The new frontiers for the United States energy security in the 2st century, Applied Energy, Vol. 76, No. 1-3, pp. 135 - 144, 2003.

[9] Costantini, V. et. al., Security of energy supply, comparing scenarios from a European perspective, Energy Policy, Vol. 35, No. 1, pp. 210-226, 2007.

[10] IEA, UNDP, and UNIDO., Energy Poverty-How to make modern energy access universal, World Energy Outlook, IEA, Paris, 2010.

[11] IAEA, Indicators for Sustainable Development, IAEA, 2004.

[12] IAEA, IEA and Eurostat., Energy Indicators for Sustainable Development: Guidelines and Methodologies, IAEA, IEA, Vienna, 2004.

[13] Feinstein, C., Economic Development, Climate Change and Energy Security-The World Bank's Strategic Perspective, ESMAP, 2002.

[14] ESCAP, Energy Security and sustainable development in Asia and the Pacific, United Nations-ESMAP, 2007.

[15] Asian Development Bank, Building a Sustainable energy future-The Greater Mekong Sub region, Manila, Asian Development Bank, 2009.

[16] Wijeyatunga, P. D. C., et. al., Strategies to overcome barriers for cleaner generation technologies in small developing power systems: Sri lanka case study, Energy Conversion and Management, Vol. 47, No. 9-10, pp. 1179 - 1191, 2006.

[17] Wijeyatunga P. D. C., Fernando, W. J. L. S., and Shrestha, R. M., Greenhouse gas emission mitigation in the Sri Lanka power sector supply side and demand side options, Energy Conversion and Management, Vol. 44, No. 20, pp. 3247 - 3265, 2003.

[18] Opathella, G. K. C., Analysis of Selected Energy Policy Options to Improve Energy Security: The Case of Sri Lanka, in School of Environment, Resources and Development, Asian Institute of Technology, Pathum Thani. 2008.

[19] Ministry of Power and Energy (MOPE) and Govt of Sri Lanka, National Energy Policy and Strategies of Sri Lanka, MOPE, Colombo, 2006.

[20] Sri Lanka Sustainable Energy Authority (SLSEA), Sri Lanka Energy balance 2007-An Analysis of Energy Sector Performance, Colombo, Sri Lanka, 2007.

[21] Ceylon Electricity Board (CEB), The Electricity Act of 2009 and the Development of the Sector, CEB, Colombo, Sri Lanka, 2009.

[22] Lefevre N., Emergy Security and Climate policy: Assessing interactions, International Energy Agency, Paris, 2007.

[23] Scheepers, M., de Jong, A. S. J., and Mater, H., EU Standard for Energy Security of Supply, ECN, 2006.

[24] Asia Pacific Energy Research Center (APERC), A Quest for Energy Security in the 21st Century-Resources and Constraints, APERC, 2006.

[25] Stirling, A., Multicriteria diversity analysis: A novel heuristic framework for appraising energy portfolios, Energy Policy, Vol. 38, No. 4, pp. 1622 - 1634, 2010.

[26] Cabalu, H., Indicators of security of natural gas supply in Asia, Energy Policy, Vol. 34, No.1, pp.218-225, 2006.

[27] Gupta, E., Oil vulnerability index of oil-importing countries, Energy Policy, Vol. 36, No.3, pp.1195-1211, 2008.

[28] Vivoda, V., Evaluating energy security in the Asia-Pacific region: A novel methodological approach, Energy Policy, Vol. 38, No. 9, pp. 5258 - 5263, 2010.

[29] 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.

[30] von Hippel, D., et. al., Energy security and sustainability in Northeast Asia, Energy Policy, In Press, Corrected Proof.

[31] Gnansounou, E., Assessing the energy vulnerability: Case of industrialized countries, Energy Policy, Vol. 36, No. 10, pp. 3734 - 3744, 2008.

[32] Percebois, J., Energy vulnerability and its management, International Journal of Energy Sector Management, Vol. 1, No. 1, pp. 51 - 62, 2007.

[33] Asia Pacific Energy Research Center (APERC), A Quest for Energy Security in the 21st Century-Resources and Constraints, APERC, 2006.

[34] Bacon, R., and Mattar, A., The Vulnerability of African Countries to Oil Price Shocks: Major factors and policy options, The World Bank, ESMAP, Washington, 2005.

[35] Vera, I., Langlois, L., Energy indicators for sustainable development, Energy, Vol. 32, No. 6, pp. 875 - 882, 2007.

[36] Gervasi, O., et. al., Energy metrics and Sustainability, Computational Science and Its Applications-ICCSA, pp. 693 - 698, 2009.

[37] Koakutusu, K., and Watanabe, R., Energy Secuirty and Developmental Needs, in Asian Aspirations for Climate Regime beyond 2012, The World Bank, 2005.

[38] Tsai, W., T., Energy sustainability from analysis of sustainable development indicators: A case study of Taiwan, Renewable and Sustainable Energy Reviews, Vol. 14, No. 7, pp. 2131-2138, 2010.

[39] Ramani, K. V., Challenges for Asia and the Pacific and lessons from UNDP projects in the region, in Energy for sustainable development, UNDP, 2004.

[40] IEA, Energy Indicators and Sustainable Development, IEA, 2001.

[41] Hainoun, A., Seif Aldin, M., and Almoustafa, S., Formulating an optimal long term energy supply strategy for Syria using MESSAGE model, Energy Policy, Vol. 38, No. 4, pp. 1701 - 1714, 2010.

[42] Urban, F., Benders, R. M. J., and Moll, H., C., Modelling energy systems for developing countries, Energy Policy, Vol. 35, No. 6, pp. 3473 - 3482, 2007.

[43] Swisher, J., N., Redlinger, R. Y., Tools and methods for intergrated resource planning: improving energy efficiency and protecting the environment, UNEP, Riso National Laboratory, 1998.

[44] D'Sa, A., Integrated resource planning (IRP) and power sector reform in developing countries, Energy Policy, Vol. 33, No. 10, pp 1272-1285, 2005.

[45] SIIT, -TU, AIT, NIES and AIM, Low-Carbon Society Vision 2030, Thailand, 2010.

[46] King, P., Low Carbon Development Path in Asia-Pacific, Institute for Global Environment Studies, 2009.

[47] Dept of Census & Statistics, National Statistics of Sri Lanka, in Statistical Appendix. Dept of Census & Statistics, Colombo, Sri Lanka, 2009.

[48] CEB, Long Term Generation Expansion Plan, CEB, Colombo, 2008.

[49] Saaty, T. L., How to make a decision: The analytic hierarchy process, European Journal of Operation Research, Vol. 48, No.1, pp 9-26, 1990.

[50] Saaty, T. L., and Saaty, R. W., Decision making in Complex Environments, SuperDecisions, 2003.

Appendix A: The list of Sub-indicators and their respective equations.

	Indicator	Equation
	Base Security	
1.	Diversification of primary energy demand-**DoPED**	$DoPED = \frac{D}{D\text{max}}$ where $D = \sum p_i \ln p_i$ And $D_{\max} = \ln T$ where, pi = share of PES in TPES, D = Shannon's Diversity Index, i = number of primary supply options
2.	Net Energy Import Dependency-**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
3.	Non Carbon Fuel Portfolio-**NCFP**	$NCFP = \frac{\text{(Hydro PED)+(NRE PED)}}{\text{Total PED}}$

	Oil Security	
4.	Oil Supply Risk Indicator-**OSRI**	$OSRI = \dfrac{\text{Domestic Reserves}}{\text{Primary Oil Consumption}}$
5.	Oil Import Intensity-**OII**	$OII = \dfrac{\text{Cost of oil imports}}{GDP}$
6.	Oil Intensity-**OI**	$OI = \dfrac{\text{Oil consumption (toe)}}{\text{GDP (US dollars)}}$
7.	Oil Share-**OS**	$OS = \dfrac{\text{Primary Oil Consumption}}{\text{Total Primary Energy}}$
	Indicator	**Equation**
8.	Net Oil Import Dependency-**NOID**	$NOID = \dfrac{\text{Oil imports in Primary Energy}}{\text{Total Primary Energy}}$
	Gas Security	The modification of Oil Security.
	Vulnerability	
9.	Energy Intensity-**EI**	$EI = \dfrac{\text{Primary Energy consumption}}{GDP}$
10.	Electricity Diversity-**ED**	Shannon-diversity index is used to measure electricity diversity. Similar to DoPED
11	Energy Bill-**EB**	$EB = \dfrac{\text{Cost of net energy imports}}{\text{GDP}}$
	Sustainability	
12.	Diversification of fuel share-**DoFS**	Similar to DoPED
13.	Non-carbon Fuel Share-**NCFS**	Similar to NCFP
14.	Renewable Fuel Share-**RFS**	Similar to NCFP
15.	Carbon Emission Intensity-**CEInt**	CO_2 emission intensity = $\dfrac{CO_2\ \text{emission}}{\text{GDP}}$
16.	Carbon Emission per capita-**CECap**	CO_2 emission per capita = $\dfrac{CO_2\ \text{emission}}{\text{Population}}$

	Energy Development	
17.	Per capita household electricity-**CapHEC**	$\frac{\text{Household Eiectricity Consumption}}{\text{Population}}$
18.	Per capita commercial electricity use-**CapCEC**	$\frac{\text{Commercial Electricity Consumption}}{\text{Population}}$
19.	Share of modern fuels in household sector-**ModFuels**	$\frac{\text{Modern Fuels in Household Sector}}{\text{Total Energy usage in Household Sector}}$