Effects of low carbon policies on the power sectors of Sri Lanka and Thailand

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Abstract—**The energy sector of a country is important in determining the competitiveness of it in the global context. The primary objective of this paper is to determine if Low Carbon policies have any impact on the energy security of the power sector of Thailand and Sri Lanka. The power sectors of the two countries are modeled using Asia-Pacific Integrated Model (AIM)/Enduse model and the energy security is assessed using three indicators which measure diversity of supply, oil share and gas share and the renewable fuel share of the power sectors. Two Low Carbon Society (LCS) scenarios are modeled for each country, named LCS1 and LCS2 along with the BAU case. The modeling horizon is 2010-2050. Results show that there is significant increase in energy security in the more advanced LCS scenario, with higher penetration of low carbon actions and measures. In addition to this, there is significant reduction in energy consumption and high mitigation of CO_2 in both the LCS scenarios.**

Index Terms—**Power sector, Low Carbon, AIM Enduse, Sri Lanka, Thailand.**

I. INTRODUCTION

Energy sector of a country is the backbone in which a country's industrial competitiveness is built. It is imperative that a well-functioning energy sector is present to facilitate the growth of a country. While developed countries do their utmost to ensure their continuous supply of energy, it is also vital that developing countries have access to a robust energy sector. In addition to this, environmental degradation brought on by the use of energy resources, specifically, the anthropogenic emission of CO_2 into the earth's atmosphere, and the negative effects of that are also of dire concern to the scientists. More decision makers are concerned with the role the energy sector plays in Greenhouse Gas (GHG) induced climate change. The world is waking up to the realization that economic growth should be attained sustainably, where the climate or the natural environment is not subjected to undue and irreversible damage.

In this context, the concept of Low Carbon Society (LCS) comes to the forefront. A LCS is a concept that refers to an economy which has a minimal output of GHG emissions into the biosphere, but specifically refers to the GHG of CO_2 [1]. The concept of LCS and sustainable development becomes more important to developing countries since this concept can also increase their competitiveness in the world market.

The primary contention of this conference paper is that Low Carbon policies increase the energy security of developing Asian countries such as Sri Lanka and Thailand. So, the power sector, which is an important and integral part of a country and its development policies, is assessed for LCS policies and the effect they have on energy security.

Sri Lanka has a population of 20 million and its power sector is primarily dependent on major hydro systems and fossil fuel powered power plants and coal fired power plants are considered in the future [2]. Thailand is the second largest economy in Southeast Asia and has a population of approximately 67 million and has a sophisticated energy system, unlike that of Sri Lanka. Both countries are net energy importers, when it comes to important energy carriers such as oil and natural gas and have developmental aspirations for which a secure energy supply system is absolutely necessary. Even though Sri Lanka is smaller than Thailand, it is evident that in the future, with growth ambitions being secured, Sri Lanka would mirror that of Thailand's state now. This is the main reason for analyzing both Sri Lanka and Thailand in this research study.

Energy security has become an important aspect in the current context, and the scientific community has carried out relevant and temporal research in this area [3-8]. In this paper, the energy security of Sri Lanka and Thailand, for the power sectors, are analysed with three indicators, which are Diversification of Primary Energy Demand (DOPED), Oil Share (OS) and Gas Share (GS) and Renewable Fuel Share (RFS). In addition to this, the energy security indices are calculated for distinct time intervals; 2011-2020 (short term), 2021-2030 and 2031-2040 (medium terms) and 2041-2050 (long term). This temporal analysis would give the palpable change of these indices over time, thus being more relevant to analyse the change of energy security in the LCS scenarios.

II. METHODOLOGY

The power sectors of Thailand and Sri Lanka are modeled and the effects of Low Carbon policies on the energy security of these sectors are analysed for a time horizon from 2010-2050. The power sector is modeled using Asia-Pacific Integrated Model (AIM)/Enduse, which is a recursive dynamic, bottom-up optimization model [9].

A. Modeling techniques

The power generation technologies are broadly categorized into carbon based generating capacities, non-carbon based generation options and renewable energy options. The carbon based generation options consider already existing technologies such as steam cycle power plants, gas turbines, combined cycles and gas engines. Another layer is added to this cluster of technologies as Carbon Capture and Storage (CCS) is also included in the future years. The non-carbon generation plants are major hydro power plants and nuclear power plants in the future. The renewable power plants include solar photo-voltaic, small hydro power plants, wind power plants, biomass based power plants, and municipal solid waste (MSW) power plants. The future power demand has to be given to the model, for the model to optimize and give the results for the CO_2 emissions and energy consumption.

The future electricity demand is calculated using a linear, multiple variable regression model, where the demand is deemed to be a linear function of the population and value added in the power sector, in the country's economy. The future GDP and population growth are obtained from governmental reports and forecasts [10]. The governing equation can be given as following:

$$\text{Electricity demand} = A \times (\text{GDP}) + B \times (\text{Population}) + C, \qquad (1)$$

Where, A is the coefficient of the independent variable of value added for the electricity sector, in USD million (at constant price, year 2002), and B is the coefficient of the independent variable of population of the country.

1) Thailand model details

The future demand, the energy price settings, and emission factor settings of the Thai power sector are given in this sub-section. Table I gives the electricity demand of Thailand. It should be remembered that the obtained electricity demand has been calibrated for the years 2020 and 2030 to reflect the demand given in the official generation expansion plan of Thailand [10].

Table II gives the energy prices of the fuels in the power sector of Thailand. The prices for 2005 and 2010 have been obtained from [11], whilst the prices for 2050 have been calculated with the escalation rates obtained in [12].

Table III gives the emission factors of the fuels used in the power sector of Thailand. These emission factors have been taken from [13].

2) Sri Lankan model details

The future electricity demand of Sri Lanka is given in Table IV.

TABLE I. THAILAND ELECTRICITY DEMAND

	2010	**2020**	**2030**	**2040**	**2050**
Electricity demand (ktoe)[A]	13,876	20,588	29,822	40,337	49,606

A: 1 ktoe = 11.63 GWh

TABLE II. THE ENERGY PRICE OF FUELS USED IN THE POWER SECTOR OF THAILAND

	Energy Price (1000 USD/toe)		
Energy type	2005	2010	2050
Coal	0.020	0.020	0.040
Lignite	0.038	0.044	0.095
Fuel Oil	0.573	0.667	1.424
Diesel	0.821	0.957	2.042
Natural Gas (NG)	0.339	0.395	0.843
Biomass	0.090	0.090	0.200
Biogas	0.176	0.205	0.437
Uranium (Nuclear)	0.020	0.023	0.050
Imported power	0.368	0.428	0.914

TABLE III. THE EMISSION FACTORS OF ENERGY SOURCES OF THAILAND

Energy type	Emission factor (kt-CO_2/ktoe)
Coal	4.20
Lignite	4.60
Fuel Oil	3.24
Diesel	3.10
Natural Gas	2.35

TABLE IV. SRI LANKAN ELECTRICITY DEMAND

	2010	**2020**	**2030**	**2040**	**2050**
Electricity demand (ktoe)	791.7	1,503.7	2,736.0	3,632.7	4,431.6

Table V gives the energy prices of fuels used in the Sri Lankan power sector. The prices for 2005 and 2010 have been obtained from [14] and the prices for 2050 have been calculated by using the escalation rates given in [12]. Table VI gives the emission factors used in the Sri Lankan power sector model [13].

TABLE V. THE ENERGY PRICE OF FUELS USED IN THE POWER SECTOR OF SRI LANKA

	Energy Price (1000 USD/toe)		
Energy type	2005	2010	2050
Coal	0.1710	0.1710	0.3776
Fuel Oil	0.4100	0.4710	1.020
Diesel	0.4800	0.5930	1.2000
Natural Gas	0.3390	0.3950	0.8429
Naphtha	0.3800	0.4110	0.9075
Biomass	0.0900	0.1050	0.2318
Uranium	0.0200	0.0233	0.0498

TABLE VI. THE EMISSION FACTORS OF ENERGY SOURCES OF SRI LANKA

Energy type	Emission factor (kt-CO_2/ktoe)
Coal	4.20
Naphtha	3.07
Fuel Oil	3.24
Diesel	3.10
Natural Gas	2.35

B. Scenario description

In addition to the BAU case of both countries, there are two LCS scenarios formulated in this research study. These LCS scenarios are named LCS1 and LCS2. The LCS1 has very low levels of counter-measures (CMs) implemented in the future years, and the LCS2 scenario has very ambitious levels of LCS CMs implemented in the future years. These two LCS scenarios serve as two levels of policy implementation that can be adhered to in Sri Lanka and Thailand.

C. Energy security

Energy security is analysed along the lines of DOPED, OS and GS and RFS.

1) Diversification of Primary Energy Demand (DOPED)

The DOPED indicator is a measure of the diversity of the energy supply of each sub-sector. The rationale for the measure of diversity indicating energy security is that the more the number of sources of energy, the more robust the energy system is, in terms of protecting itself from scarcity of an energy source. The indicator is adopted from the Shannon-Weiner Index, and is presented in [6].

$$\text{DOPED} = \frac{1}{D_{\max}} \sum_{i=1}^{n} -\ln p_i * p_i \qquad (2)$$

Where $$\text{D}_{\max} = \ln n \qquad (3)$$

Where,
n is the total number of different energy types and
p is the fraction of each energy type as a ratio of the total primary energy supply in the power sector.

2) Oil Share (OS) or Gas Share (GS)

The OS is an indicator of how dependent the energy system is on oil. Oil energy resources are considered important to energy security because they are a commodity traded in world markets and most energy systems are dependent on imported oil sources [3, 6]. This is true of the two countries and their energy systems analysed in this research study as well. Both Sri Lanka and Thailand are, to a considerable extent, dependent on imported oil. The GS is mathematically formed in the same way as the OS, but with just NG in place of oil. This indicator is applicable only to Thailand, since Sri Lankan power sector isn't dependent on NG. But the OS is used only for Sri Lanka and not for Thailand, since oil is predominantly used in Sri Lanka, and not so much in Thailand.

$$\text{OS} = \frac{\text{Oil Supply (ktoe)}}{\text{Total Primary Energy Supply (ktoe)}} \times 100\% \qquad (4)$$

$$\text{GS} = \frac{\text{Gas Supply (ktoe)}}{\text{Total Primary Energy Supply (ktoe)}} \times 100\% \qquad (5)$$

3) Renewable Fuel Share (RFS)

The rationale for RFS indicating the energy security of a sector is the implicitly held notion that renewable fuels are mostly domestically available [6]. For example, small hydro power generation supply is classified as a renewable fuel, and in Thailand and Sri Lanka, it is an endemic and domestic source of energy supply.

$$\text{RFS} = \frac{\text{Renewable fuel supply (ktoe)}}{\text{Total Primary Energy Supply (ktoe)}} \times 100\% \qquad (6)$$

III. RESULTS

This section presents the results of the Sri Lankan and Thai power sectors in terms of energy consumption, CO_2 emissions, and the energy security indices.

A. Energy consumption

The energy consumption in the power sectors of Thailand and Sri Lanka are given in Figs. 1 and 2, respectively. It can be seen that in both Sri Lanka and Thailand, the LCS scenarios bring about a reduction in the consumption of energy. This is due to the CMs implemented in the LCS scenarios. Even in that, the LCS2 scenarios show higher reduction in energy consumption. Also, the energy reductions become more pronounced in the longer term, when compared to the near-term years.

In Fig. 2, the BAU case shows an exponential increase in the energy consumption in the Sri Lankan power sector. There are two main reasons for this. One reason is the expected large increase in electricity consumers and customers, as the government hopes to increase electrification. Another reason is the limitation of the availability of major hydro sources in Sri Lanka.

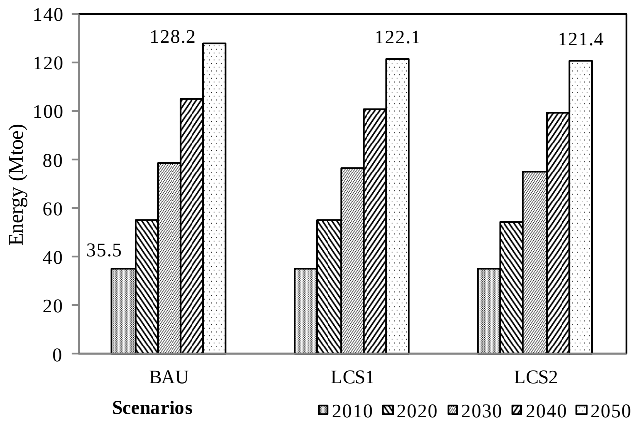

Fig. 1. Energy consumption in the Thai power sector

The non-availability of any more major hydro sources would lead to the installation of fossil and coal powered plants which would increase the energy consumption drastically.

Table VII gives the energy savings in the LCS scenarios, when compared to the BAU case, in the Sri Lankan and Thai power sectors. These energy savings are broken down into four distinct time periods, which would give an indication as to how the scenarios bring about energy reductions. Temporally, it can be seen that the highest reductions in energy consumption happen in the latter time period of the modeling horizon. In the case of Sri Lanka, there is a drastic increase in the energy savings in the LCS2 scenario, in 2041-2050, since the CMs are aggressively pursued and the power plants have very high efficiencies, in this time period. But, in the case of Thailand, the difference in savings in the 2041-2050 timeframe is not very significant. The reason for this is the aggressive proliferation of CCS in the LCS2, which affects the energy efficiencies of the power plants, thus reducing the energy savings effect.

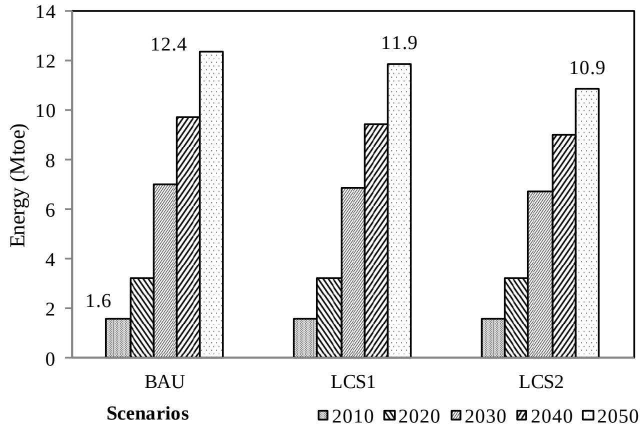

Fig. 2. Energy consumption in the Sri Lankan power sector

TABLE VII. THE COMPARATIVE ENERGY REDUCTIONS IN THE LCS SCENARIOS

Scenarios	Incremental Energy Savings (Mtoe)			
	2011-2020	2021-2030	2031-2040	2041-2050
Thailand				
LCS1	0.0	10.9	38.0	53.2
LCS2	1.2	20.6	52.4	59.3
Sri Lanka				
LCS1	0.011	0.5	1.4	3.9
LCS2	0.011	1.0	4.8	11.9

B. CO_2 emissions

Figs. 3 and 4 give the CO_2 emissions in the Thai and Sri Lankan power sectors for selected years. In Fig. 3 it can be seen that there is a drastic reduction in emissions in the LCS2 scenario, so much so that there seems to be peak in the emissions, thus indicating there is de-coupling between electricity demand and the emissions from the power sector. The emissions in 2050, in the LCS2 scenario (126.2 Mt-CO_2), is less than half of the expected emissions in the BAU case (275.6 Mt-CO_2).

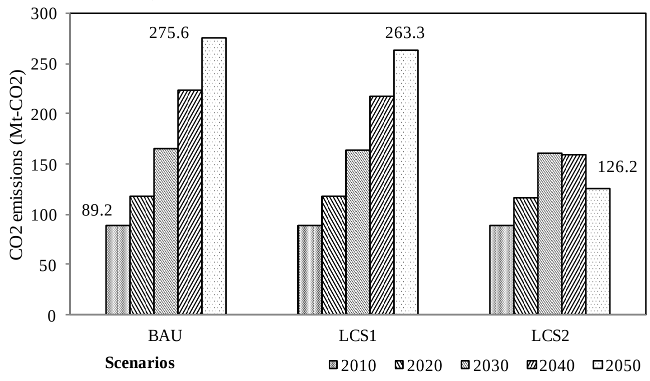

Fig. 3. CO_2 emissions in the Thai power sector

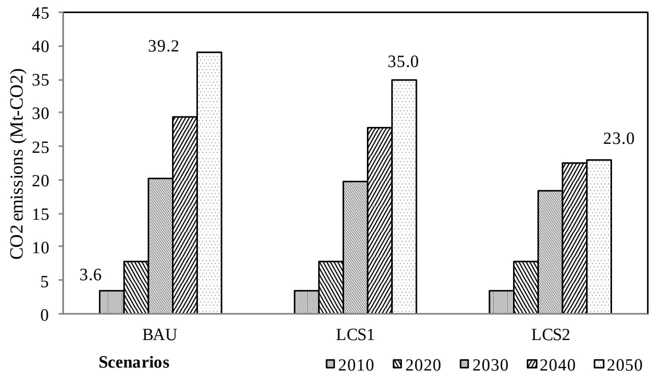

Fig. 4. CO_2 emissions in the Sri Lankan power sector

In Fig. 4, the CO_2 emissions in the Sri Lankan power sector don't show as drastic a reduction as the Thai power sector. One of the main reasons for this is that the rate of adoption of CMs in the Sri Lankan power sector is modeled more circumspectly, in lieu of the fact that the Sri Lankan power system is not as sophisticated as Thailand. Hence, even though there is significant reduction, it is not possible to see a peak-CO_2 emission pattern, as can be seen in the LCS2 scenario of Thailand.

Table VIII gives the CO_2 mitigations in the LCS scenarios of Sri Lanka and Thailand, when compared to their respective BAU cases. These results also reiterate the drastic reduction possible in the LCS2 scenarios of Thailand and Sri Lanka. In the time period of 2041-2050, there is 10 times more mitigation in CO_2 in the LCS2 scenario of Thailand, than the LCS1 scenario. Most of the mitigation is achieved by both the dissemination of renewable energy resources as well as CCS measures.

C. Energy security

This section presents the energy security results of the Thai and Sri Lankan energy security indices, which are DOPED, OS/GS and RFS. The obtained values for these indicators are reported for the year 2010 and then their values for the cumulative primary energy supply for the years 2011-2020 (2020-CUM), 2021-2030 (2030-CUM), 2031-2040 (2040-CUM), and 2041-2050 (2050-CUM) are presented here. The reporting of the cumulative values increases in tracking the temporal nature of change of energy security.

TABLE VIII. THE COMPARATIVE CO_2 MITIGATIONS IN THE LCS SCENARIOS

Scenarios	CO_2 mitigation (Mt-CO_2)			
	2011-2020	2021-2030	2031-2040	2041-2050
Thailand				
LCS1	0	5.9	35.4	92.2
LCS2	1.4	21.9	346.4	1,079.5
Sri Lanka				
LCS1	0	1.9	8.7	29.1
LCS2	0	7.6	42.3	116.9

1) Diversification of Primary Energy demand – DOPED

The DOPED values of Thailand and Sri Lanka are given in Figs. 5 and 6, respectively. It can be seen that in both the countries, the diversity is enhanced which implies that there is an increase in energy security in the LCS scenarios, when compared to the BAU case. In the BAU case of Thailand, energy security steadily increases even if the status quo is maintained, but, the LCS2 scenario increases it continuously, into the future.

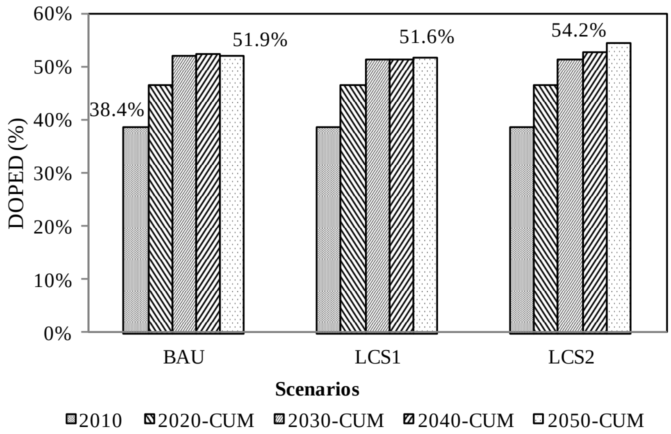

Fig. 5. The DOPED levels in the Thai power sector

In the case of Sri Lanka, in the BAU case, the DOPED increases in value and then decreases in the period leading up to 2050. This trend is reversed in the LCS2 scenario and thus this leads to a more secure power sector.

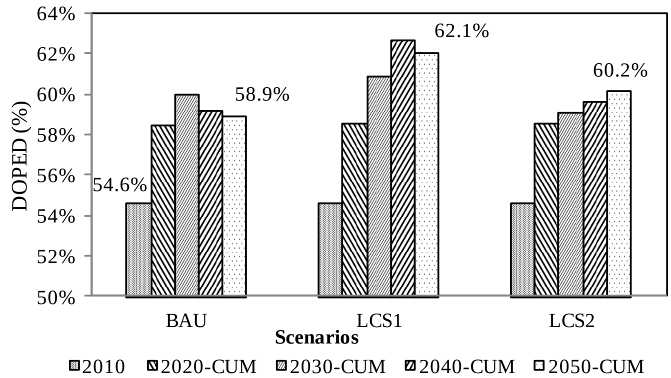

Fig. 6. The DOPED levels in the Sri Lankan power sector

2) Gas Share (GS) and Oil Share (OS)

The GS of Thailand and the OS of Sri Lanka are given in Figs. 7 and 8, respectively. There is a palpable reduction in the use of NG in the LCS2 scenario, which indicates that the power sector of Thailand uses less NG and thus becomes more energy secure. On the other hand, the LCS1 has no significant impact on the energy security of Thailand, in terms of GS.

With respect to OS of Sri Lanka, there is a drastic reduction in the OS in the LCS2 scenario, thus indicating there is a significant increase in the energy security of Sri Lanka. But, as with Thailand, the LCS1 scenario doesn't have a major impact on OS, and hence doesn't increase energy security significantly.

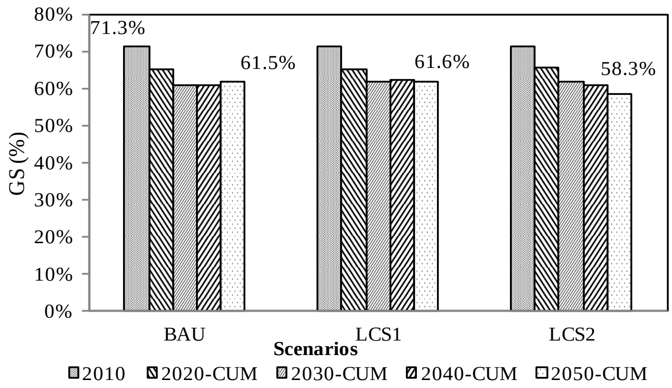

Fig. 7. The GS levels in the Thai power sector

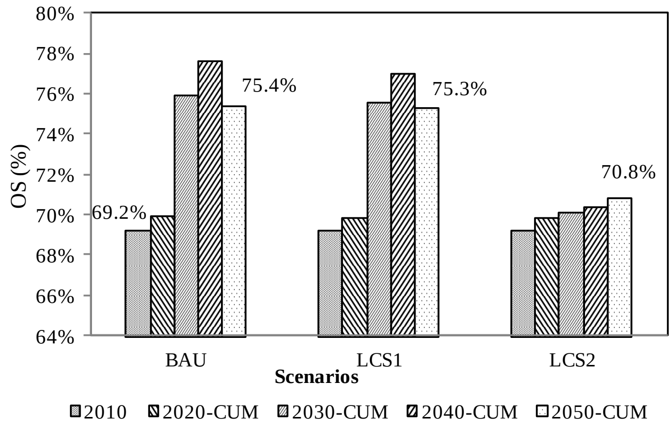

Fig. 8. The OS levels in the Sri Lankan power sector

3) Renewable Fuel Share – RFS

Figs. 9 and 10 give the RFS values of Thailand and Sri Lanka, respectively. As with the other indices, RFS shows an increase in the Thailand LCS2 scenario, thus indicating there is a significant increase in energy security.

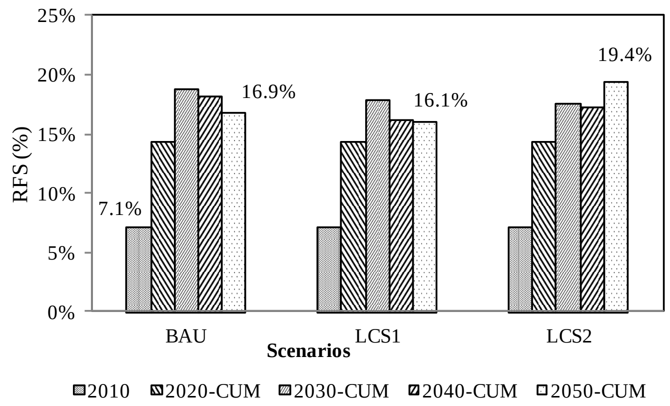

Fig. 9. The RFS levels in the Thai power sector

In the case of Sri Lanka, in 2010, the RFS value is very high, but in the BAU case, it continues to decline drastically, since the government has no plans of developing indigenous renewable sources. But, in both the LCS1 and LCS2 scenarios in the Sri Lankan power sector, there is a significant increase in the RFS values. This is important as it shows that LCS scenarios increase energy security when renewable resources are available and can be used effectively.

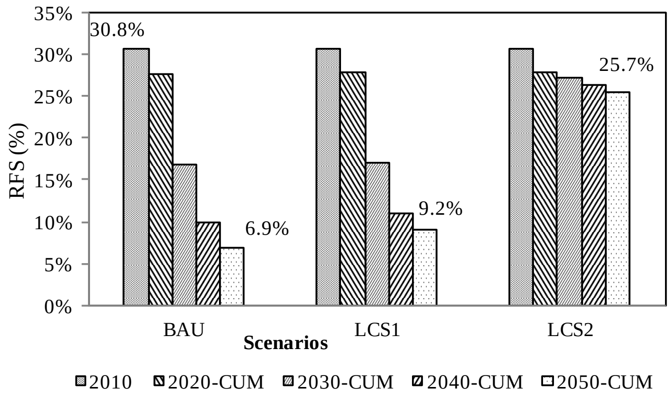

Fig. 10. The RFS levels in the Sri Lankan power sector

IV. CONCLUSION

The power sectors of Thailand and Sri Lanka are modeled for the BAU case, along with two LCS scenarios, LCS1 and LCS2. In the case of Thailand, there is a cumulative mitigation of 1.4Gt-CO_2, compared to the BAU case from 2010-2050, in the LCS2 scenario. Along with this there is considerable increase in DOPED, and RFS, and considerable reduction in GS, which leads to higher energy security. Even though, there is no significant increase in energy security in the LCS1 scenario, this scenario still leads to energy consumption reductions and emission mitigation. In the case of Sri Lanka, again there is a cumulative mitigation of 160 Mt-CO_2, compared to the BAU case, from 2010-2050. In addition to this, there is significant enhancement of energy security as well, when measured by DOPED, OS and RFS.

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