Assessment of Nationally Determined Contributions of Sri Lankan Power Sector

Anushanka Dahanayake[1], Gayashika Fernando[2], Migara Liyanage[2]
[1]School of Civil and Mechanical Engineering, Faculty of Science and Engineering, Curtin University
Kent St, Bentley WA 6102, Australia
[2] Faculty of Engineering, Sri Lanka Institute of Information Technology
New Kandy Rd, Malabe 10115, Sri Lanka.
i.dahanayake@student.curtin.edu.au, gayashika.f@sliit.lk, migara.l@sliit.lk

ABSTRACT

The nationally determined contributions (NDCs) aim to attend long-term temperature goals, which have been imposed by the Paris agreement to strengthen climate change efforts. Fossil fuel is the major energy source in power generation in Sri Lanka, contributing 67% of total input energies. Sri Lanka is intended to achieve 70% renewable energy in the power sector by 2030 and achieve carbon neutrality in the power sector by 2050 through its NDCs. This study analysed the NDCs in the Sri Lankan power sector. The study was carried out through Asia-Pacific Integrated Assessment Model (AIM/End-use), a recursive dynamic least-cost optimisation framework based on bottom-up modelling principles. The Sri Lankan Power sector has been categorised into a few sectors based on the fuels used in power generation. It mainly considers thermal coal, thermal oil, and hydro. It will also consider all the existing power generation technologies, committed technologies and technologies identified as candidates. A business-as-usual scenario (BAU) and three alternatives NDC were considered in this study. These NDCs include enhancing renewable energy by adding 3867 MW, converting existing fuel oil-based combined cycle power plants to natural gas and establishing new natural gas plants, and improving the efficiency of transmission and distribution network (lost reduction 0.5% compared with BAU by 2030). The study analysed the output data and confirmed the feasibility of meeting GHG emission reduction targets through consideration of selected NDCs in the time span of 2020-2030. The GHG emissions from the BAU scenario and three countermeasure scenarios were analysed in 2015-2050. The input primary energy supply was determined to compare the variation in energy with the effect of NDCs.

KEYWORDS: *Power Sector, Nationally Determined Contributions, Sri Lanka, AIM/Enduse,* CO_2 *Mitigation.*

1.0 INTRODUCTION

Sri Lanka is a middle-income country located near the equator and experiences tropical climate throughout the year. Since ancient times Sri Lanka has had an agriculture-based economy. The country's economy gradually transformed into an agricultural and industrial-based economy. Modern technology heavily impacted society and lifestyles. Sri Lankan GDP has significantly risen after the civil war in 2009 until the Covid-19 global pandemic. Major development projects and the vast improvement of tourism have resulted in economic growth in the recent past. Continuous and uninterrupted electricity supply is a must for a developing country to achieve its economic goals. To satisfy the rising electricity demands in the country, expansion in the power generation sector is essential. With the rise of demand, a large amount of energy is required to fulfil the demand. In the past, most of the electricity demand was supplied using hydropower, and a small percentage was supplied using fossil fuel-based thermal power plants. However, with the demand rising, the country had to consider other generating options. At that time, the significant factor was cost efficiency and rapid installation. As a result, many fossil fuel-based thermal powers were commissioned during the past few decades. Because of that, today, 51.65% of electricity is generated by using fossil fuel-based

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thermal power plants(The Generation Planning Unit Transmission and Generation Planning Branch Ceylon Electricity Board Sri Lanka, 2019)

The Parsi agreement was established in 2015 in response to global climate change concerns. The agreement aims to keep global warming well below two degrees of Celsius (preferably 1.5°C) compared to pre-industrial levels. The Paris accord empowers countries to determine their own long-term Nationally Determined Contributions (NDCs). Nationally Determined Contributions can be thought of as the heart of the Paris Agreements, as they detail each country's specific greenhouse gas (GHG) mitigation efforts over a specified time period.(UNFCCC, 2015).

Sri Lanka submitted the first NDCs to the UNFCCC secretariat in 2015, and an updated version was submitted in July 2021. Sri Lanka's updated NDCs cover a range of different sectors. However, for the purposes of this study, consideration is limited to NDCs in the Sri Lankan power sector. Given that the power sector accounts for a sizable portion of the country's GHG emissions, assessing the power sector's NDCs enables decision-makers to gain a better understanding of future energy and emission patterns. Additionally, assessing NDCs is critical for achieving the global and local energy-environmental targets defined.

According to the Ministry of Environment Sri Lanka, the updated NDCs are based on more recent analysis and include strategies for mitigating and adapting to climate change over the period considered (2021 -2030). For the power sector, a total of five NDCs have been submitted. The county expects to reduce GHG emissions by 25% (5% unconditionally and 20% conditionally) between 2021 and 2030 by implementing the five NDCs. Identifying future GHG emission scenarios' possible challenges and predictions are essential when reaching the determined GHG emission targets in the power sector. Modelling is a powerful tool for analysing the power sector and assisting decision-makers in achieving future sustainable targets in the power sector(Ministry of Environment, 2021)
There were no recent studies that analysed the effects of NDCs on the Sri Lankan power sector.

However, several similar studies have been carried out for the Sri Lankan and regional contexts in the recent past. Emissions in the different sectors like transport, industrial, agricultural and power have been modelled in previous studies. Different types of energy modelling scenarios have been considered in each study. Country and regionally based scenarios must use the forecasting technique most appropriate for the country or the region. Most of the studies used modelling techniques to predict GHG emissions, but their analysing aims were different.

Sugathapala, 2020 is a recent study that carried out in the Sri Lankan context to assess multi-criteria energy sector mitigation action. This study analysed the 52 nationally appropriate mitigation actions (NAMAs) to identify their pros and cons. The studies state that NAMAs submitted by Sri Lank has mainly focused on marginal abatement cost and are not very much concerned with other factors, such as co-benefits, enablers and barriers. However (Sugathapala, 2020) has a different objective; it did not specially focus on the power sector, but all the energy sectors generally.

(Selvakkumaran & Limmeechokchai, 2017) is a study that was carried out to assess Sri Lankan and Thailand Power sectors. The study aimed to assess how Low Carbon Scenario (LSC) affects both countries' power sectors in the case of mitigating CO2, techno-economic results, energy security, and marginal abatement cost. The AIM Enduse model had been used to model the power sectors. However, this study did not focus on analysing the NDCs, and it mainly focused on various aspects of the LSC scenario. Since this study used the older version of the Sri Lankan Long Term Generation Plan, some of the data could be changed with the new plan. Unavailability of NDCs at that time and latest government policies were adapted according to the NDCs, and lack of consideration of economic factors can be identified as the major drawbacks.

2.0 METHODOLOGY, SCENARIOS AND DATA

2.1 Modelling Framework

The modelling was performed by using the AIM/Enduse model, which was developed in the late 90s by the National Institute for Environmental Studies in collaboration with Kyoto University, Mizuho Information & Research Institute and several research institutes in the Asia-Pacific region

(AIM Project Team, n.d.). The AIM/Enduse model is a recursive dynamic bottom-up optimisation model capable of selecting detailed technologies inside a country's energy economic environment system. The technology selection is based on the least cost optimisation framework. The power sector of Sri Lanka was modelled considering all existing and potential future expansion technologies. Modelling considers the BAU scenario with three countermeasure scenarios. The three countermeasures' scenarios are based on selected NDCs for the study.

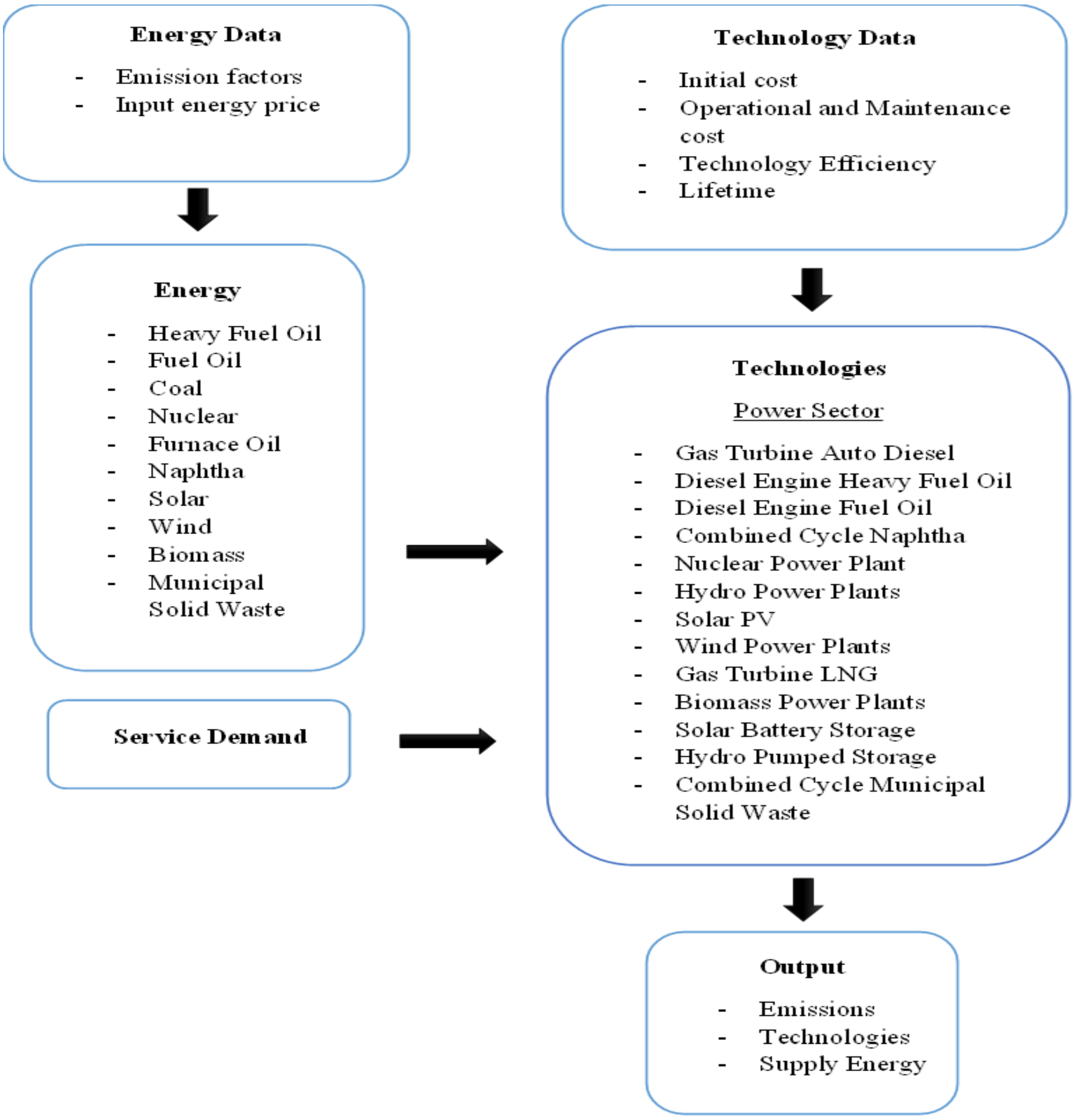

Figure 1 Schematic Diagram of Modelling Framework

2.2 Scenario Development

Three countermeasure scenarios were developed using the AIM/Enduse model in addition to the business as usual scenario. The first step in modelling was to define and model the BAU scenario. The business as a scenario was developed in accordance with CEB's current expansion strategy. There is a total of five NDCs under the power sector of Sri Lanka. Among them, three countermeasure scenarios were selected for analysis in the study. The NDCs are selected based on the possibility of the model using the AIM/Enduse model. The NDC 01, NDC 03, and NDC 04 were used to model countermeasure scenarios (CMs)(Ministry of Environment, 2021). Each countermeasure was described in accordance with the applicable NDC/NDCs.

Table 1 Scenario Description

Scenario	Relevant NDC/ NDCs	Description
CM01	NDC 01	The scenario focuses on enhancing renewable energy contribution (RE) by adding 3867 MW. Solar PV, wind, hydro and sustainable biomass share was increased.
CM02	NDC 01 & NDC 03	The scenario focuses on employing the effect of CM01 + conversion of existing Fuel Oil-based power plants to natural gas (NG) and the establishment of new NG plants*. (Cumulative effect of NDC 01 & 03)
CM03	NDC 01, NDC 03 & NDC 04	The scenario focuses on employing of CM01 + CM02 + 0.5% transmission and distribution loss reduction*. (Cumulative effect of NDC 01, 03 & 04)

Each countermeasure scenario evaluates the effect of NDCs on the Sri Lankan power sector in terms of reducing GHG emissions, supplying primary energy, and distributing end-use energy. The effect was calculated by combining NDC 01 and NDC 03 in CM02, as the NDCs are intended to be applied concurrently in the actual scenario. By examining the cumulative effect of NDCs in two countermeasure scenarios, it is possible to compare the effect of each NDC to the cumulative effects of NDCs.

CM01 and CM02 were directly modelled using AIM/Enduse. The respective technologies' share was varied to achieve the NDCs' in the selected time frame. CM01 was achieved by increasing the share of renewable technologies (devices) respective to BAU.

Countermeasures can be implemented in the model utilising a variety of different ways. Three viable methods to define countermeasure scenarios in the model are managing the renewable share, stock quantity, and recruited quantity. Additionally, the combination of three methods can be utilised to create scenarios with the desired service share. Between 2021 and 2030, Countermeasure scenario CM01 focuses on boosting existing renewable energy. According to the data, the expansion of renewable capacity in NDC 01 nearly doubles the existing share of renewable energy. That is, the NDC 01 can be met by approximately doubling the existing renewable capacity. The existing renewable share was doubled in the model in order to achieve the aims of NDC 01. In Countermeasure scenario CM02, the additional LNG share was added to Countermeasure scenario CM01. The cumulative addition of renewable share and LNG share was incorporated into the CM02. The countermeasure 03 was manually calculated using the CM02 enduse energy results. From 2021 onwards, the effect of the 0.5% efficiency improvement in transmission and distribution network was evenly distributed across all generation options in the CM02. When modelling the CM03, it was assumed that the reduction in net electricity generated by efficiency improvement was distributed evenly across all generation technologies in the CM02.

2.3 Data Collection

This study relies heavily on historical data. This model required data on the Sri Lankan power sector in a wide range of input energies to output emissions. Numerous studies conducted by various institutions served as a significant source of data.

The primary data required to construct the model were device/technology-related data. Technology data consisted of installation costs (initial cost), operational and maintenance costs of technologies, emission factors, lifetime and efficiencies. Additionally, the model relied heavily on primary input energy data and end-user electricity demand data. The data obtained from the sources were converted to the appropriate units before being entered into the model. Technology data inputs are most of the times input as per device unit. The primary data collection sources for the model are listed in table 2.

Table 2 Data Sources

Source	Author	Year
Long Term Generation Expansion Plan (2020 – 2039)	Ceylon Electricity Board	2019
Updated Nationally determined contributions, Sri Lanka	Ministry of Environment	2021
Sri Lanka Energy Balance - Sri Lanka	Sustainable Energy Authority	2018
Development of a small scale IGCC power plant using solid waste at Hambantota, Sri Lanka	Charith Liyanage	2013
Emission of greenhouse gases from waste incineration in Korea	Kum-Lok Hwang, Sang-Min Choi, Moon-Kyung Kim, Jong-Bae Heo, Kyung-Duk Zoh	2017
Study Report on Use of Battery Energy Storage Systems	Public Utilities Commission of Sri Lanka	2015

3.0 RESULTS AND DISCUSSION

3.1 Energy and Emissions in BAU Scenario

The main primary energies, which are inputs to the Sri Lankan power sector, are classified into five groups and are represented in figure 17. Energies are represented for 2015-2050 respective to the BAU scenario. Annual energy consumptions based on primary energy sources are represented in figure 2. Diesel oil, fuel oil, heavy fuel oil, and naphtha are all types of petroleum oil. Other renewable energy sources include solar, wind, and biomass. The classification system is intended to facilitate the process of representing and studying.

Coal was the most consumed primary energy source in Sri Lanka's power sector in 2015 (modelling start year), accounting for 54.72 GJ. In comparison to other energy sources, it accounts for 50.18 %. Petroleum oil was the second most consumed energy source in 2015, accounting for 28.68 % of consumption (3098 TJ). Hydropower accounts for 18.18% of total energy consumption (1967 TJ). In 2015, no municipal solid waste incineration power plants were operational, and the consumption of other renewable energy sources was 2.33 %. According to the model predicted primary energy consumption in future years, the coal energy supply tends to increase rapidly. The main reason for the increase in the amount of coal power plants can be identified as broadly available, and it is cheaper than petroleum oils. Moreover, the BAU scenario does not consider any technology changes; therefore, the model prioritises the least cost technology to fulfil the rapidly increasing energy demand. However, a significant reduction in petroleum oil consumption can be seen after 2030. The primary reason for the decline could be the retirement of several large petroleum oil-fired power plants in 2020-2030.

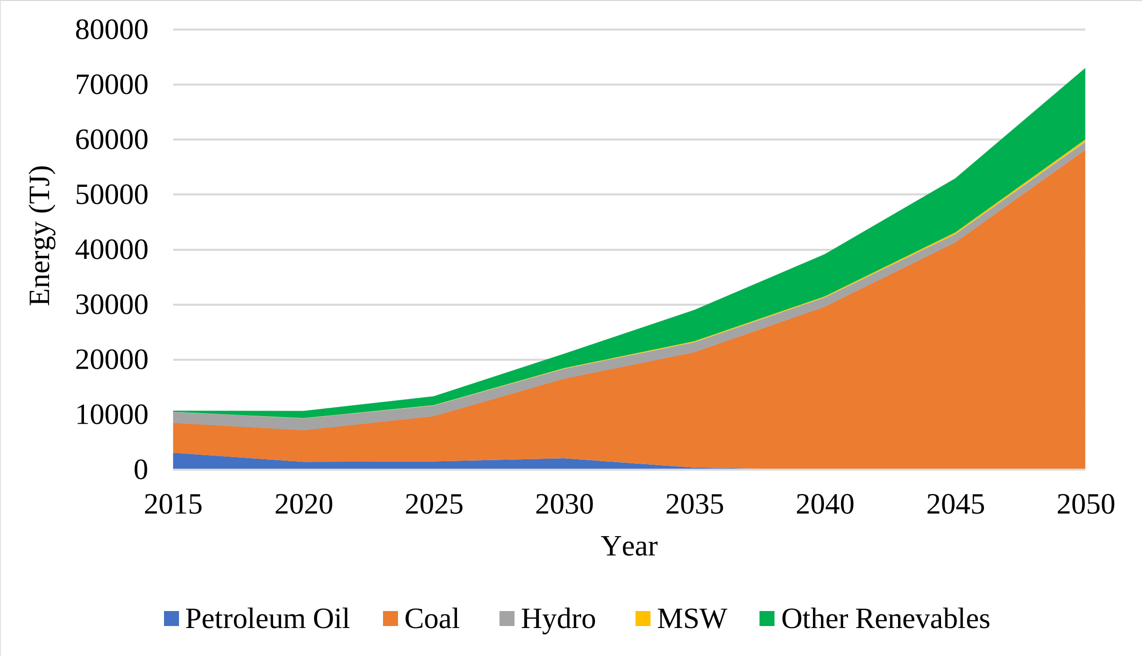

Figure 2 Primary Energy Consumption in BAU scenario 2015-2050

The area chart in figure 3 depicts the power sector's GHG emissions in the BAU scenario by energy type. The charts demonstrate unequivocally that coal power plants will contribute significantly to GHG emissions. The percentage increase in emissions from coal power in 2050 relative to 2015 is 962 %, and coal power will account for more than 98 % of emissions in 2050. Since country's expansion strategies prioritise reducing reliance on petroleum oil-based electricity production, petroleum oil-based generation emissions cannot be expected to increase significantly after 2030. Even though the mid-2030s will phase out petroleum-based energy generation, coal-fired power plants will continue to meet growing electricity demand. The country's primary challenge would be to reduce coal generation in the future in order to meet global climate goals.

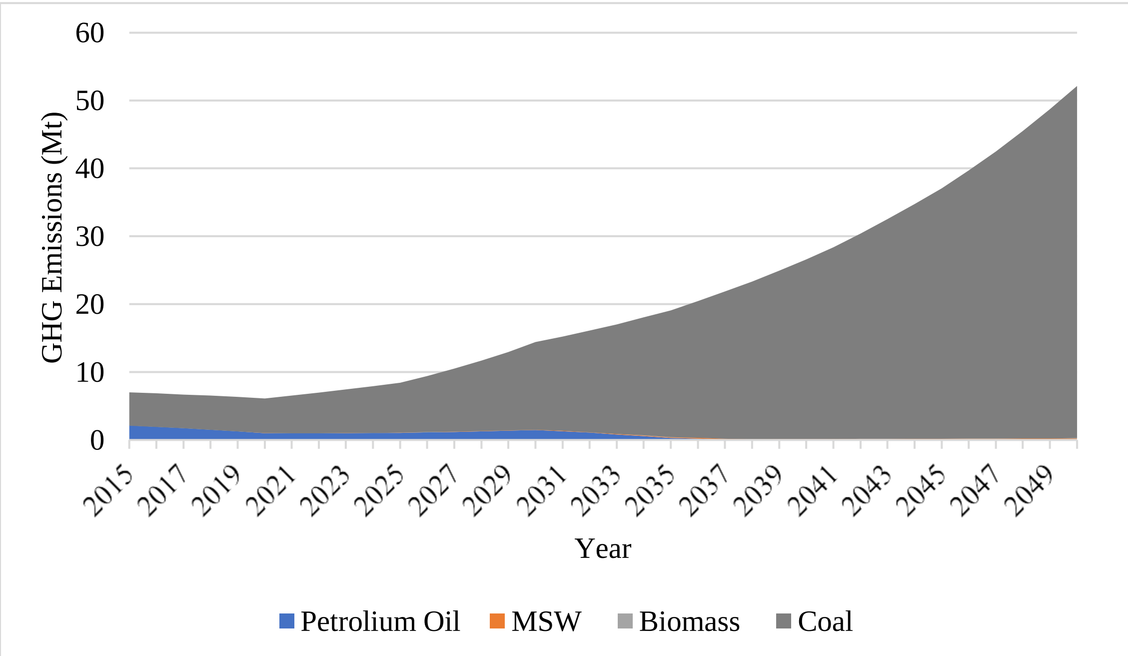

Figure 3 Emissions in BAU scenario 2015-2050

3.2 Countermeasure Scenarios

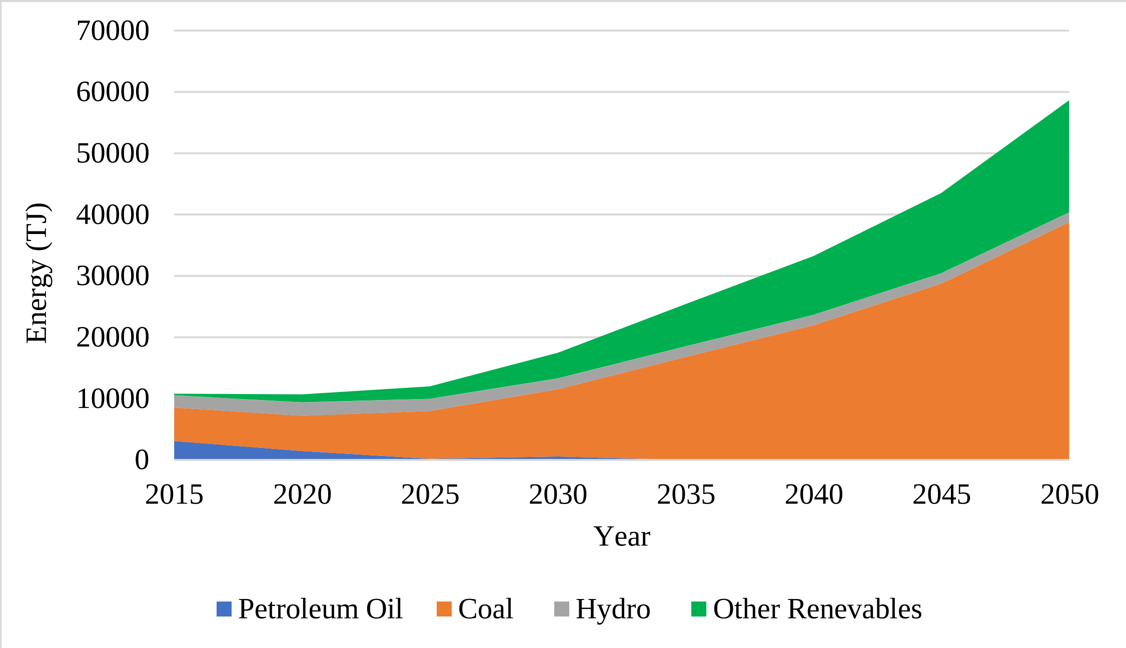

Figure 4 Primary Energy Consumption CM01 scenario 2015-2050

The Countermeasure scenario CM01 aims to enhance the renewable energy contribution to the national generation mix by adding a renewable capacity of 3867 MW. The effect of NDC 01 is completely taken into account in countermeasure 01. The renewable addition is expected to implement by establishing rooftop, small-scale and large-scale solar PV and wind power generations.

By increasing solar and wind energy, CM01 increases the renewable energy share. It has a significant impact on the significant increase in the share of other renewable energy sources. Renewable energy generation was 2.33 % in 2015, and with the implementation of NDC 01, it will increase to 31.11 % in 2050. Most significantly, coal consumption can be reduced by 17165.88 TJ by 2050; this represents a 33 % reduction compared to BAU. Respectively in 2030 and 2040, the coal consumption reduction will be 24% and 26%. The increase in hydro share is only 13% compared to BAU in 2050. Since the major hydro has the higher initial cost model attempts to minimise the selection of major hydropower in future expansions. Moreover, the model does not select the municipal solid waste (MSW) power plants for the expansion under the effect of NDC 01. The high initial and high O&M costs can affect the elimination of MSW in CM01.

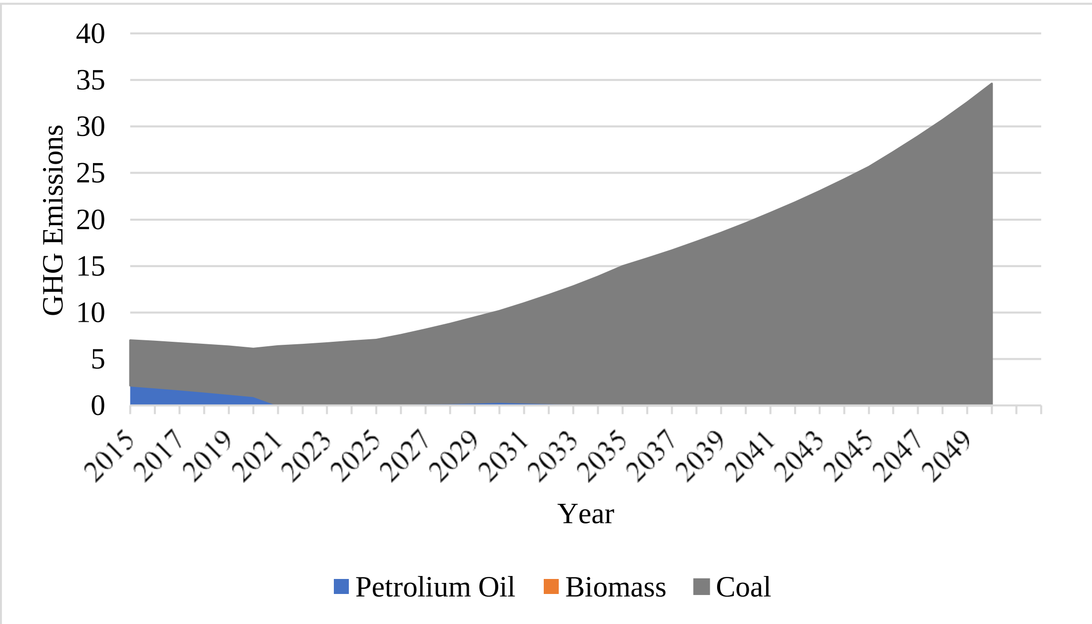

Figure 5 GHG Emissions in CM01 for 2015-2050

The addition of renewable energy to CM01 significantly reduces total emissions. Coal-fired power generation emissions will increase by 608% by 2050 compared to 2015. In 2050, CM01 would have reduced emissions from coal power generation by 355% compared to the BAU scenario. The CM01 results indicate that the NDC 01 significantly reduces emissions from coal power generation by meeting a significant portion of growing electricity demand and limiting coal power expansion. Given that many thermal power plants are scheduled to retire between 2020 and 2030, the additional renewable energy capacity added during that time period assists in meeting the power supply reduction caused by the absence of petroleum-based power plants

The Countermeasure scenario CM02 absorbs the effect of NDC 03 along with the NDC 01. NDC 03 aims to convert existing petroleum oil-based combined cycle power plants to Natural Gas and establish new natural gas plants. Conversation of 600MW fuel oil-based power plants to NG and 700 MW new combined cycle power plants in place of anticipated coal power capacity addition in the BAU.

In comparison to the BAU scenario, the CM02 scenario emphasises the inclusion of LNG power plants. LNG could provide 12% of the country's annual energy requirements in 2050. LNG additions may be beneficial in order to maximise GHG reductions. According to CM02, coal consumption will be reduced by 29056 TJ or 27.48 % by 2050. When CM01 is compared to CM02, the individual effect of NDC 03 can be determined. When COM02 is compared to CM01, CM02 reduces coal consumption by an additional 13.96% and increases other renewable energy consumption by 1.61% in 2050. Even though other renewables consume the same amount of energy in 2050 as CM02, their share has increased. The primary reason for this could be the addition of LNG to CM02, as higher LNG efficiencies can result in an increase in the share of other renewables in CM02, even if consumption remains constant. Higher efficiencies of LNG can reduce the total requirement of primary energy; due to that, a minor increase in other renewable shares can occur.

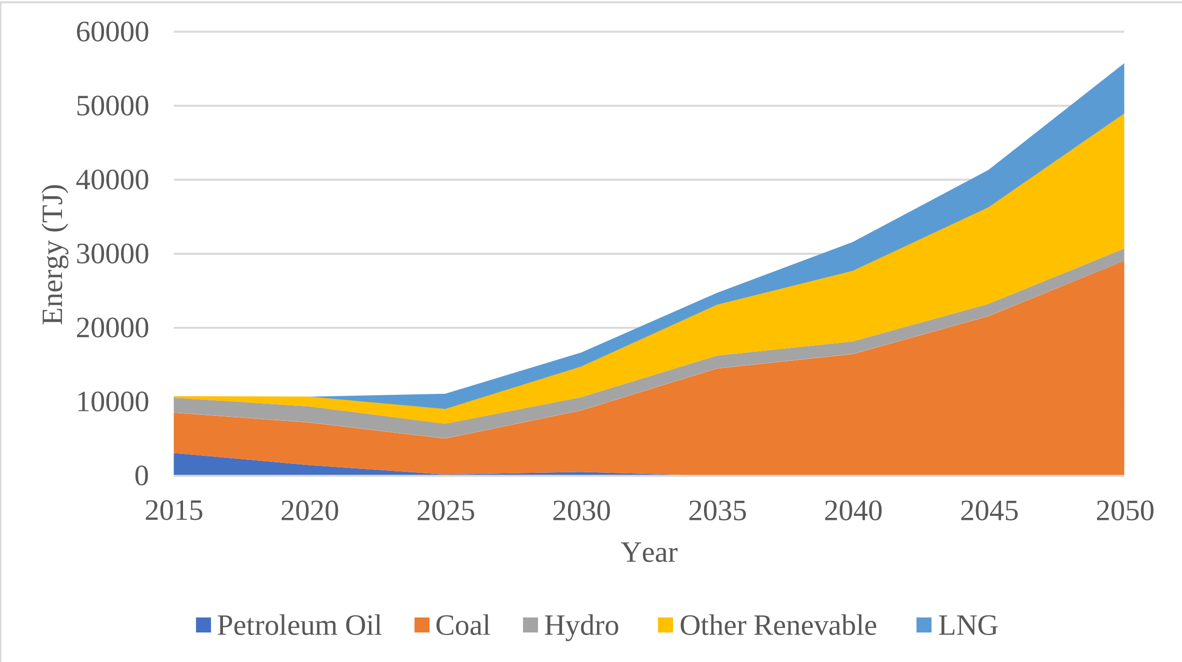

Figure 6 Primary Energy Supply in CM02 2015-2050

The countermeasure scenario absorbs the effect of NDC 03 along with the NDC 01. NDC 03 aims to convert existing petroleum oil-based combined cycle power plants to Natural Gas and establish new natural gas plants. Conversation of 600MW fuel oil-based power plants to NG and 700 MW new combined cycle power plants in place of anticipated coal power capacity addition in the BAU.

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LNG additions and conversions of existing combined cycle power plants to LNG demonstrate a considerable reduction in GHG emissions from coal. Coal emissions will be reduced by 43% relative to BAU and 24% compared to CM01 in 2030. However, LNG produces additional emissions. CM02 has reduced GHG emissions by 15% when LNG and coal emissions are combined, compared to coal emissions in CM01. Even though the inclusion of LNG increases GHG emissions slightly, it has the effect of reducing GHG emissions when compared to CM01, which did not include LNG additions. The decrease percentage does not substantially increase beyond 2030, remaining between 12 and 16 per cent, while the amount reduced increases from 1.45 Mtonne in 2030 to 5.17 Mtonne in 2050. However, LNG addition enables a considerable reduction in GHG emissions in Sri Lanka's power sector.

The conversion of existing combined cycle plants causes the reduction in petroleum oil-based generation emissions significantly from 2021. The cumulative emissions from petroleum oil-based generations from 2021 -2030 will reduce from 2.04 Mtonne to 1.88 Mtonne, accounting 16.4% reduction. The emissions from biomasses are not significant compared to coal and LNG emissions. The focus of renewable addition highly based on solar and wind technologies results in low biomass emissions.

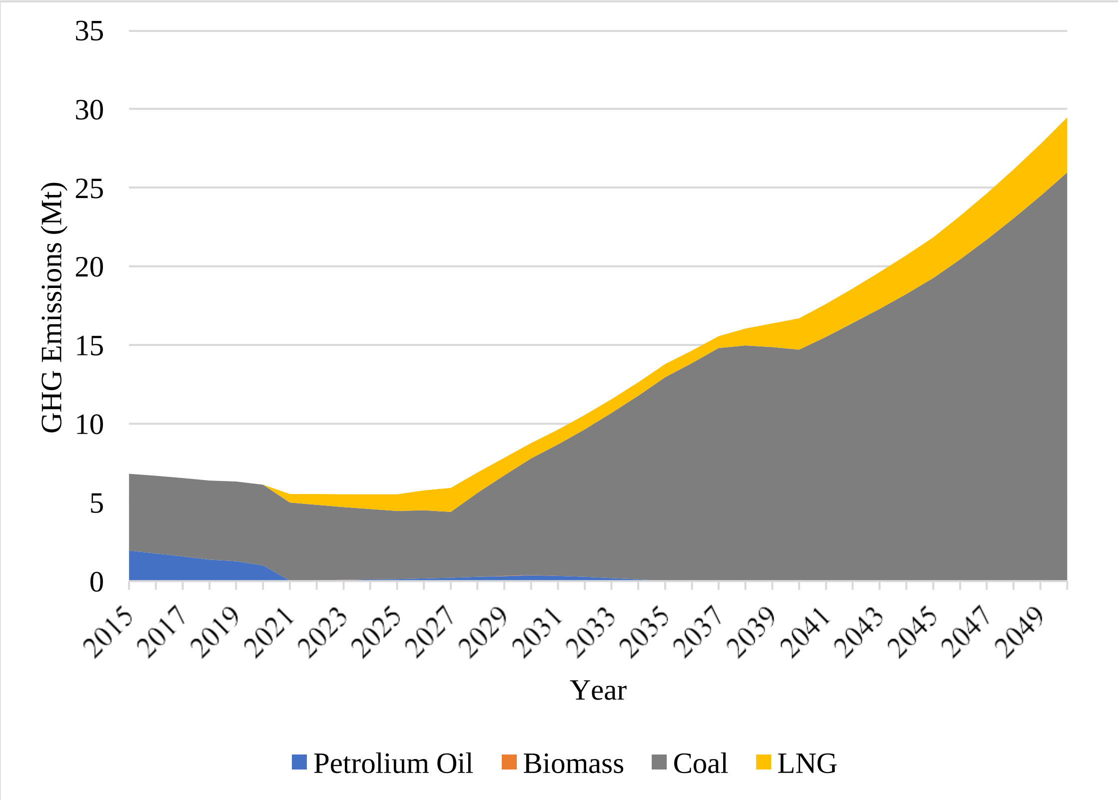

Figure 7 Emissions in CM02 scenario 2015-2050

Countermeasure 03 combines the effects of NDC 04 and CM02. CM03 was used to account for the cumulative effect of the three NDCs evaluated in the study. NDC 04 is an additional NDC that is taken into account in the CM03. The primary energy consumption and GHG emission graphs for CM03 are similar to the graphs of CM02. The slight reduction in GHG emission and primary energy supply does not show any visible changes compared to the graph of CM02. Therefore, the graphs for the CM03 are not presented in the paper. In NDC 04, the country aims to increase the efficiency of its transmission and distribution networks by reducing losses by 0.5 % compared to BAU in 2030. Between 2021 and 2030, the NDC is expected to save approximately 6652.8 TJ of energy.

The primary energy consumptions result of CM03 and CM02 does not show a significant difference. Since the efficiency improvement is slight, the difference between CM03 and CM02 is not visible in yearly primary energy consumption.

The GHG reduction in CM03 compared to CM02 is not significant. However, when the total generation rises, the amount of GHG emitted will be increased gradually. In 2030 the reduction of GHG compared to CM02 is 167 TJ, and in 2050 the reduction amount will rise to 615 TJ (257% increase). The effect of NDC 04 affects the GHG reduction in the long term due to the increase of the service demand.

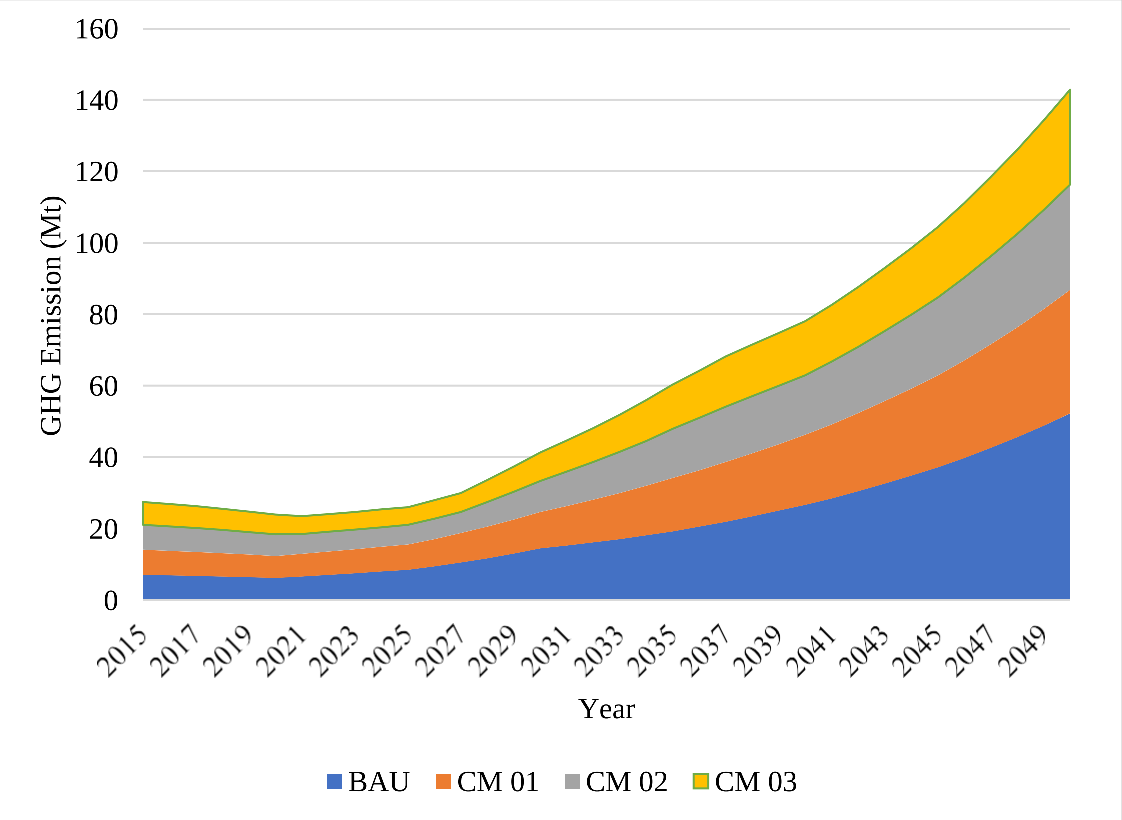

Figure 8 GHG Emissions from all scenarios 2015-2050

The power sector's GHG emissions increase primarily in lockstep with demand growth. As the country's GDP increases, its energy demand increases proportionately, increasing the requirement of rapid power generation capacity expansion. Incorporating high carbon primary energies and technologies cause high GHG emissions due to the rapid expansion. In the BAU scenario, the GHG emissions increase rapidly with the rise of the power supply. Many GHG emitting technologies would have been implemented in future in the BAU scenario. In the BAU scenario, predicted GHG emissions were increased from 41.16 Mtonne compared to 2025 in 2050. In the years 2025, 2030, 2035, 2040, and 2050, NDC 01 alone will be able to reduce GHG emissions by 16.46%, 29.37%, 21.7%, 26.3%, 30.8%, and 33.67 %, respectively. As demonstrated in figure 5, the CM01 is able to minimise GHG emissions with the rise of electricity generation capacity. Since the model is based on least-cost optimisation methods, the selected technology mix is optimised for economic benefit. The CM01 is controlled by incorporating renewable technologies such as solar PV and wind for the generation mix. The model output GHG emission results shown above illustrate the effect of the addition of renewable generation technologies, which contributes to reducing the emission in CM01 compared to BAU.

CM02 includes LNG additions as well as LNG conversions of existing fuel oil plants along with the effects of CM01. To examine the impact of NDC 03 on its own, the impact of CM02 must be subtracted from the impact of CM01. CM02 line in figure 8 shows the obvious reduction of GHG emissions with respect to CM01. Predicted GHG emission reductions compared to CM01 are 18.37%, 9.89%, 6.29%,10.96%,10.30% and 9.87% respectively in years 2025, 2030, 2035, 2040, 2045, and 2050. Since the LNG replaces the coal additions in future expansion, LNG has 40%-50% lesser CO2 emissions compared to coal power plants. Compared to BAU, CM02 is able to minimise the GHG emissions by 34.83%, 28.0%, 37.31%, 41.10% and 43.54% in five years gaps from 2025 to 2050. The GHG reduction percentage was decreased from 34.83% to 28.0% from 2025 to 2030. The primary cause of the decrease can be attributed to the model parameter limitations used in CM02 to model NDCs. NDC 04 in reducing GHG emissions is minimised because the NDC only aim to incorporate minor efficiency improvement to the transmission and distribution grid. Therefore the 0.5% efficiency gain directly applies to the GHG reduction due to reduction in total energy before transmission. The calculations assume that the effect of 0.5% efficiency gain equally affects all generation technologies.

4.0 CONCLUSION

The study has assessed the Sri Lankan power sector by considering the effect of Nationally Determined Contributions for the period of 2015 -2050. Selected three NDCs from the latest NDCs of Sri Lanka were used to develop countermeasure scenarios in the study. The AIM/Enduse model was selected as the modelling tool for the study. The CO_2 equivalent GHG emissions were considered when analysing the emissions from the power sector.

In the business-as-usual scenario, GHG emissions will increase by 643% in 2050 compared to 2015. The increase in the power sector emissions is drastically caused by coal power expansion options and fossil fuel-based generation options. The significant growth in coal power generation after 2030 can be identified as a major challenge the country must overcome when meeting the global energy and environmental targets.

The countermeasure scenarios based on the NDCs have a significant impact on reducing GHG emissions and share of coal power generation. According to CM03, the coal supply will be reduced from 27.63%, and the total GHG emissions will be reduced from 43.8% by 2050. The addition of LNG in CM02 also has a significant effect. The major share of coal power expansion will be occupied by the LNG, which has a lower percentage of GHG emissions than coal power plants.

The effect of the NDC04 (0.5% efficiency improvement of transmission and distribution network) is not much significant when compared with the other two NDCs, but it is also capable of saving a greater amount of energy with the growth of demand.

The study's findings comprehensively highlight the impact of NDCs on Sri Lanka's electricity sector between 2021 and 2030 and beyond. The selected NDCs 01 and 03 provide significant support for reducing GHG emissions and coal use. However, consideration of additional mitigation options beyond 2030 is necessary to meet the nationally and globally established sustainable development targets.

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