Climate Policy Assessment for Climate Change Mitigation and Carbon Neutrality: A Case Study of Sri Lanka

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Declaration

I, with this, declare that to the best of my knowledge, this submission is my work. It neither contains direct material previously published nor written by another person or material which, to a substantial extent, has been accepted for the award of any other academic qualification of a university or other institute of higher learning except where acknowledgment is made in the text.

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Abstract

Climate change is one of the most significant challenges faced by mankind in the 21st century. Human activities, particularly in the energy supply and demand sectors, primarily cause an increase in greenhouse gas (GHG) emissions. The Paris Agreement's climate goal aims to limit global warming to a level well below 2°C above pre-industrial levels, with a specific target of limiting temperature rises to 1.5°C by the end of this century. Therefore, there has been an emphasis on achieving large-scale reductions in GHG emissions from the energy sector.

After the initial stocktake in 2023, it is apparent that global emission pathways are not meeting the expected progress toward the Paris Agreement targets. Swift actions are necessary to readjust these pathways. Consequently, the reduction of greenhouse gas emissions in developing economies will be pivotal in reaching the desired global temperature targets. This study examines the case of Sri Lanka, a developing economy with low carbon intensity, to explore the role of similar economies in acachievingthe Paris targets

Sri Lnaka has has a population of 22 million and a GDP of 84.5 billion USD in 2021. The predicted economic growth in the future could result in a rapid increase in energy demand in the country. This could result in an increase in fossil fuel use and subsequent carbon emissions. Sri Lanka has pledged to mitigate 14.5% of the GHG emissions conditionally and unconditionally by 2030 compared to its 2021 levels through its Nationally Determined Contributions. However, it aspires to achieve ambitious targets like carbon neutrality by 2050.

Moreover, it also tries to increase the share of renewable energy in electricity generation from 45% in 2021 to 70% in 2030. However, it needs a pragmatic plan to facilitate a smooth transition towards reducing these emissions. A systematic analysis of different policy options and scenarios is required to determine a suitable policy for reducing GHG emissions. In doing so, Energy-Economic-Environmental models can provide the basis for such analysis. The development

of such models for Sri Lanka and the carrying out of scientific studies are still at an early stage.

This thesis covers the analysis of different scenarios for climate change mitigation using an energy-economic-environmental model in the case of a developing economy with low carbon intensity. The scientific questions to be answered in this study are: 1) How is the energy environmental system of an developing economy modeled considering both energy consumption and supply sectors? 2) What is the impact of carbon taxes on reducing carbon emissions? 3) How could energy, economic, and environmental models be used to analyse climate futures? 4) What scenarios will lead the country to carbon neutrality? 5) How do efficient technologies, renewable energy sources, cleaner fuels, nuclear energy, carbon capture and storage technologies, and green hydrogen for power generation reduce emissions? 6) What are the marginal abetment costs of CO_2 reduction for proposed emission mitigation actions? 7) What impacts do low-carbon scenarios have on energy security? 8) What are the other co-benefits of CO_2 mitigation?

The first objective of this study is to develop a bottom-up type of energy system model for a developing economy with low energy intensity. Sri Lanka has chosen as a case study, considering the economic and demographic factors to assess energy use and its environmental implications during a given period. This model comprehensively assessed the integrated reference energy system, encompassing energy supply and demand sectors during a planning horizon. It used a recursive dynamic cost optimization approach, minimizing the energy system's total cost each year during the planning period from 2015 to 2050. The AIM/Enduse model, a part of the Asia Pacific Integrated Modeling family, was used to develop an energy system model for the Sri Lankan energy sector. It considered a Business-As-Usual scenario (BAU) and other scenarios for achieving large-scale reductions in CO_2 emissions. The BAU scenario assumes existing economic, demographic, and social trends throughout the modeling period. It assumes the continuity of current policy measures across all five energy sectors throughout the modeling period. According to the model results, the total

primary energy supply in the BAU scenario is expected to increase almost threefold, from 11 Mtoe in 2015 to 34 Mtoe in 2050. The CO_2 emissions associated with energy use will increase from 19 Mt in 2025 to 66 Mt in 2015 at an average annual growth rate of 7%. The increase in CO_2 emissions is attributed to the use of fossil fuels, as their share is expected to increase from 53% in 2015 to 66% in 2050. The results indicate that if there is no policy intervention, the share of fossil fuels will continue to increase, resulting in a significant increase in CO_2 emissions.

The second objective of this study is to examine the impact of carbon taxes on achieving large-scale emissions reductions in the energy sector. It employed five carbon tax trajectories proposed by the MESSAGE-GLOBIOM Integrated Assessment Consortium to achieve five levels for the global mean temperature. These targets will be achieved by imposing five different carbon tax trajectories ranging between 2.3 US$/t$CO_2$ and 436 US$/t$CO_2$ in 2050. The reference scenario for Sri Lanka was assumed to be in the middle of the road pathway defined in the Shared Socioeconomic Pathways. According to the model results, CO_2 emissions at these carbon tax levels could be reduced by 25% to 60% by 2050. It also has other benefits, such as reduced primary energy supply and final energy consumption by 2050. Nevertheless, the research findings imply that aggressive carbon mitigation measures and taxes are required to achieve significant emission reductions in developing economiew.

One of the main objectives of this study was to develop scenarios for achieving carbon neutrality by 2050. It defined four countermeasures: namely, plausible, ambitious, challenging, and stringent scenarios involving the level of intervention on the energy demand and supply sides. These scenarios considered different technology options and policy measures, such as the diffusion of efficient technologies, the availability of renewable energy sources, the use of cleaner fuels, nuclear energy, carbon capture and storage technologies, and green hydrogen for power generation. The results of this study revealed that a stringent scenario that includes aggressive policy measures in both the energy supply and

demand sectors, use of renewable energy for power generation, diffusion of efficient end-use devices, fuel switching, increasing the share of electric cars, and public transport achieves a near carbon-neutral scenario at a carbon tax trajectory of 32 US$/tCO$_2$ in 2020 and 562 US$/tCO$_2$ in 2050. The net energy import dependency will decrease to 13% in 2050 compared to the BAU scenario (65%) under the near carbon neutral scenario, which is a positive outcome from the energy security perspective.

The fourth objective of the study was the development of future emission pathways and the estimation of energy and environmental implications for different emission pathways using the model. The fifth IPCC assessment report analysed the energy system and related emissions under five shared socioeconomic pathways representing possible climate futures. These pathways include SSP1: Sustainability Pathway, SSP2: Middle of the Road Pathway, SSP3: Regional Rivalry Pathway, SSP4: Inequality Pathway, and SSP5: Fossil-fueled Development Pathway. The findings of this study reveal that the SSP5, which reflects rapid economic growth, higher utilisation, inefficient and traditional end-use technologies, firm reliance on abundant fossil fuel resources, and a lower level of awareness of sustainability and the environment in the future, will provide the highest primary energy supply of 44.6 Mtoe in 2050. The lowest primary energy is recorded under the SSP4, and it was 26.5Mtoe in 2050. The CO_2 emissions in 2050 were highest under SSP5 with 107Mt and lowest under SSP1 with 24Mt in 2050. Out of all scenarios, SSP5 had the highest energy intensity with 6MJ/US$ and a carbon intensity of 0.25kg/ US$ in 2050. The SSP1, which characterized a sustainable pathway, resulted in a primary energy consumption of 27Mtoe and 17Mt CO_2 emissions in 2050. It developed different climate futures that could provide valuable insights into how energy and emissions change.

The final objective of this study is to analyse the co-benefits of carbon reduction and to estimate the marginal abatement cost of CO_2 reduction. This study examined the co-benefits of reducing CO_2 emissions under these emission

reduction targets. The co-benefits analysed include a reduction in primary energy supply, net energy import dependency, energy security, and the level of local air pollutants (NOx and SO_2). Six different indices collectively define the country's energy security, including the diversity of primary energy demand, non-carbon fuel share, renewable fuel share, oil share, primary energy intensity, and carbon intensity. Mitigating 90% of CO_2 emissions compared to BAU will result in 21% of net energy import dependency. It also provided a 1.8 Shannon index for the diversity of primary energy demand, indicating a higher diversity of energy types. Meeting this reduction target would result in carbon intensity levels of 0.01kg/US$ and energy intensity levels of 2.4MJ/US$ in 2050, representing approximately a 90% and 80% reduction, respectively, compared to 2015 levels. This study also analysed the economic costs of reducing CO_2 emissions and developed sector-level marginal abatement cost curves. These play a critical role in deciding policy options for reducing CO_2 emissions. Five countermeasure scenarios, with CO_2 emission reduction targets between 10% and 90%, were used to develop marginal abatement cost curves. According to sectorial marginal abetment cost curves, the most economical CO_2 emission mitigation option would be introducing efficient and hybrid road vehicles, using efficient residential technologies such as refrigerators and air conditioners, and biomass for residential cooking. The highest mitigation potential will be possible by introducing electric buses for public transport and large-scale wind and solar energy generation.

The study's findings indicate that aggressive policies introducing clean energy and efficient technologies are required to reduce large-scale CO_2 emissions. Renewables (solar and wind) and nuclear energy for power generation will significantly reduce emissions. Considering the limitations in land availability, biomass is expected to play a limited role. In addition, it would require efficient end-use devices, switching to alternative fuels such as liquified LNG, using electric cars, and expanding public transport. Nevertheless, it would bring additional advantages such as improved energy security, reduced energy imports, and

reductions in the levels of local air pollutants. Reducing emissions will require a marginal abatement of carbon for Sri Lanka, which will vary from 197USD/tCO_2 to reduce 10% to 1792USD/tCO_2 to reduce 90% by 2050. The results indicate that the marginal abatement cost for CO_2 reduction is higher than the global average for developing conomies.

Publications

The following publications were produced from this study. The co-authors Prof. Migara Liyanage, Prof. R.A. Attalage, Prof. S. Karunarathne, and Dr. Gabrial Anandharaja contributed in a supervisory capacity.

Peer-reviewed Journals (International)

1. Gayashika L. Fernando, Migara H. Liyanage, Gabrial Anandarajah, Rahula A. Attalage, Shiromi Karunaratne," Achieving near-zero carbon dioxide emissions from energy use: The case of Sri Lanka," Sustainable Production and Consumption, Volume 40,2023, Pages 236-25 1,ISSN 2352-5509, https://doi.org/10.1016/j.spc.2023.06.024. (H Index 60, Impact Factor 12.1).

Peer-reviewed Conferences (International)

1. G.L Fernando,M.H Liyanage, "The Potential Role of Carbon tax in Achieving Paris Agreement Targets for a Developing Country: A Case Study of Sri Lanka", The International Conference on Utilities and Exhibition on Energy, Environment and Climate change (ICUE), Pattaya City, Thailand, 2020.
2. G.L. Fernando, G.N. Samarasekara and M.H. Liyanage, "Energy and Environmental Implications of Green House Gas Mitigation Policies in the Transport Sector of Sri Lanka," Green Energy for Sustainable Development, Phuket, Thailand, 2018.

Preparation in Progress (Peer-reviewed Journals -International)

1. G.L. Fernando GL, M.H. Liyanage, "Role In Carbon Tax in Achieving Paris Agreement Targets; The Case of Sri Lanka" Journal of Climate Policy (Q1 -H Index 71, Impact Factor 5.85)
2. G.L. Fernando GL, M.H. Liyanage, "Shared Socioeconomic pathways for analysing climate futures; The Case of Sri Lanka" Journal of Climate Policy (Q1 -H Index 71, Impact Factor 5.85)

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Abbreviations

AAGR	Average Annual Growth Rate
ADB	Asian Development Bank
AIM	Asian Pacific Model
ASF	Atmospheric Stabilisation Framework
BAU	Business-As-Usual
BU	Bottom-Up
CI	Carbon Intensity
DTPED	Diversity of Total Primary Energy Demand
EEE	Energy Economic Environmental
ETSAP	Energy Technology System Analysis Program
FEC	Final Energy Consumption
GDP	Gross Domestic Product
GDPP	Gross Domestic Product Per Capita
GHG	Greenhouse Gases
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IMAs	Integrated Assessment Models
IPCC	Intergovernmental Panel on Climate Change
LCS	Low Carbon Scenarios
LEAP	Low Emissions Analysis Platform
LTGEP	Long-Term Generation Expansion Plan
MAC	Marginal Abetment
MARIA	Multiregional Approach for Resources and Industry Allocation model
MARKAL	Market ALlocation model
MESSAGE	Model for Energy Supply Systems and their General Environmental impact
MiniCAM	Mini Climate Assessment Model
NCFS	Non-Carbon Fuel Share
NDC	Nationally Determined Contributions
NEED	Net Energy Import Dependency
NIES	National Institute of Environmental Studies
OECD	Organization for Economic Cooperation and Development
OS	Oil Share
PEI	Primary Energy Intensity
RCP	Representative Concentration Pathways
RETScreen	Renewable Energy Technology Screening Model
RFS	Renewable Fuel Share
SGM	Second Generation Model
SLCPP	Sri Lanka Climate Prosperity Plan
SLSEA	Sri Lanka Sustainable Energy Authority
SRES	Special Report on Emissions Scenarios
SSP	Shared Socioeconomic Pathways

TD	Top-Down
TIMES	The Integrated MARKAL-EFOM System
TPES	Total Primary Energy Supply
UNFCCC	Convention on Climate Change
WEM	World Energy Model