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Net-Zero Emissions Strategy using LEAP: a Case Study of Pakistan

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Abstract

Pakistan's energy and electricity sector has not performed well over the years due to improper planning, policy formulation, and implementation. Due to this, a large amount of greenhouse gases is being emitted by Pakistan, which harms the environment in our area. To follow the Paris Climate Agreement goals to limit the increase below 2oC by 2100, many developing countries in aim for achieving net-zero emissions target and sustainability, are facing several economical and technical challenges. Therefore, energy planning based on demand, consumption, supply, and cost must be created to meet a nation's emissions reduction target and to ensure a sustainable energy future. To achieve this purpose in Pakistan, the study works on energy modelling, which by integrating into energy policies, net-zero emissions along with other co-benefits in terms of energy security and cost can be achieved. The study finds that in the WEM (With Existing Measures) scenario involving energy efficient technology, emissions are projected to be reduced by 16.2% from the reference value by 2040. While in the WAM (With Additional Measures) scenario involving renewable energy technology, emissions would be reduced by 75% to 85%, which is considered as 'Net-zero'. The WEM scenario performs well due to energy efficient technology, which results in less emissions than the reference scenario, while also improving energy security and cost. Whereas WAM scenario produces the least emissions of the three scenarios due to the involvement of around 80% energy from renewable technology. It is expected that this study's outcomes will be useful to help energy policy makers in following feasible socio-economic pathways to cut greenhouse gas emissions in achieving the net-zero emissions aim, enhancing energy security, and energy equity for sustainable energy future.

Keywords: Net-zero emissions, Energy security, Energy cost, Energy equity, Low Emissions Analysis Platform

Introduction

The changing climate caused by Earth getting warmer due to gases like carbon dioxide is a big and serious problem for the whole world. Rising global temperatures due to GHG emissions demand urgent action. Recently, the goal of achieving "net zero" emissions by 2050 has become a central focus in global climate politics. Net zero involves balancing carbon emissions with carbon removal, aiming to prevent harmful climate change [1].

The Paris Agreement aims to limit the increase below 2◦C, reducing emissions soon and achieving balance by the century's midpoint. 192 states and the EU, covering 98% of emissions, approved it [2,3]. China aims for carbon neutrality by 2060, India by 2070, and the EU and others by 2050 [2]. Developing nations strive for growth while addressing air pollution-related deaths and energy equity. Reliance on imported fossil fuels threatens energy security. Sustainable electricity options, from renewables such as solar and wind power sustainable solutions is an alternative to Pakistan's electricity crises as well as GHG emissions [4]. Fossil fuels being the source of air pollution cause greenhouse gases (GHGs) emissions and other environmental pollutants, including CO, N2O, SO2, CO, and VOC. [5]

Key contributors to greenhouse gas (GHG) emissions include CO2 (54%), CH4 (36%), N2O (9%), CO (0.75%), and VOC (0.3%) [6]. The energy and transport sectors account for about half of Pakistan's national greenhouse gas (GHG) emissions, with the agricultural sector contributing 39%, as per a 2008 national inventory. [7]

Pakistan, heavily reliant on oil and gas, is projected to produce 4,200 million tons of pollution by 2050. The country will need 361 million tons of oil-based energy by 2030, with a projected population of 403 million by 2100 [8,9-12]. Solutions involve transitioning to cleaner energy sources, such as recycling, solar power, and hybrids, along with tree planting. Challenges include high initial costs, potential job losses, and energy supply imbalance with electric cars [10]. This study aims to explore Pakistan's path to net-zero emissions, considering environmental impact, energy security, and cost control. The findings can guide developing countries, promoting sustainable practices for a better future.

To reduce emissions there is a need for Pakistan to shift away from its reliance on fuels as evidenced by its per capita emissions of 1.8 tons in 2020 (compared to the global average of 4.9 tons) and transition towards renewable energy sources. Pakistan faces challenges with energy generation capacity with a reserve margin of 31%. To ensure energy security it is crucial to diversify energy sources by integrating energy options. However, the high production costs at Rs13.29 per kWh (compared to the average of Rs5.61) pose affordability issues that disproportionately affect low-income households and hinder access to energy.

In order to tackle these challenges effectively this study aims to develop a framework, for modeling and decision making in the long-term planning and policy development of Pakistan’s electrical system. The development of an energy modeling for Pakistan’s sustainable electrical system is the desired goal of this project.

Methodology

This study utilizes LEAP (Low Emissions Analysis Platform) to analyze Pakistan's emissions and energy indicators, aiming to assess benefits like reduced greenhouse gases, enhanced energy security, and lower costs through increased capacity and improved efficiency. The main procedures followed in the study consists of following steps:

- In accordance with the 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories, a national GHG emissions estimation model including all energy generation activities that release GHGs has been developed.
- Utilizing an energy model, and estimating the energy demand, capacity, cost, generation, and emissions projections for the base year 2022 and future projection till 2040 under the reference scenario.
- Establishing policy intervention scenarios, WEM (With Existing Measures) including energy efficient technology and WAM (With Additional Measures) consisting renewable energy technology involvement in the energy sector as a planning strategy for net zero emission.
- A comparison and analysis of the results from the reference and policy intervention scenarios that highlight the impacts on the environment, and energy security and cost.

Key Assumptions for Input in LEAP Model

Electricity demand predictions are based on economic and demographic factors. Data from various sources, including NTDC and Energy Yearbook, were used for modeling, considering factors like GDP, growth rates, sector-specific power consumption, customer numbers, population, and households.

Table 1. Key Assumptions

Key Assumptions	Base Year (2022)	Growth (%) Reference Scenario	Source
Households	34.5 million	Population [Million People]/ Household size [People]	Growth (Pop Growth Rate [%]/100)
Population	235.8 million	1.7%	Pakistan Economic Survey 2021-22
GDP	362.6 billion US$	6%	NTDC
Household Size	6.3 People	-	
Income	2 thousand US$	6%	Pakistan Economic Survey-2015

1. Main Assumption: It enables the provision of the model's main variables, such as demographic information, economic statistics, and associated entries.
2. Demand: In this module, numerous energy demand categories and sectors are covered are specified for system.
3. Transformation: It includes a variety of supply and conversion technologies of the model and related emission factors must be considered.
4. Resources: All energy sources, both primary and secondary, that are relevant to the resource's module mentions the model.

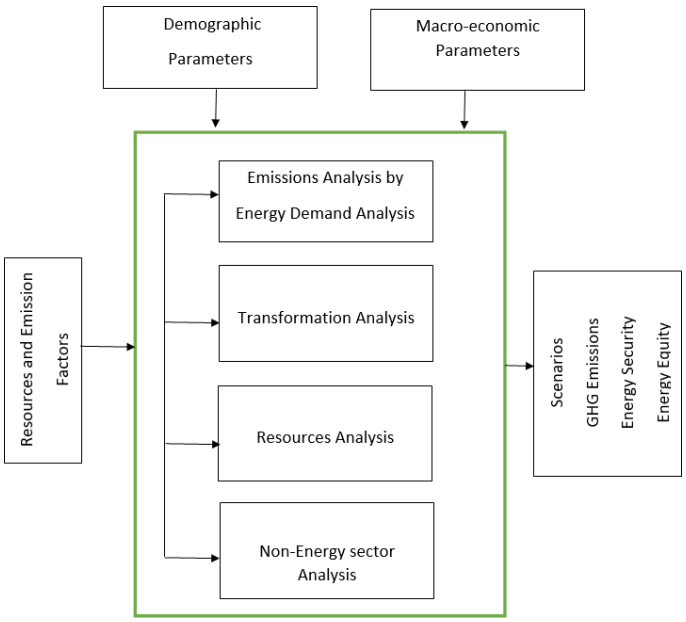

Figure 1. LEAP Structure Flow Chart

RESULTS AND ANALYSIS

Electricity Demand (Reference & WEM scenario)

Projected electricity consumption in Pakistan is set to rise significantly from 184 TWh in 2022 to 820 TWh in 2040, driven by population growth, urbanization, and economic factors. The Reference scenario indicates higher demand from domestic and industrial sectors. While in WEM, energy-saving measures may reduce

total demand to 692 TWh in 2040. The WAM also scenarios show similar trends as of WEM in demand assumptions throughout the study period.

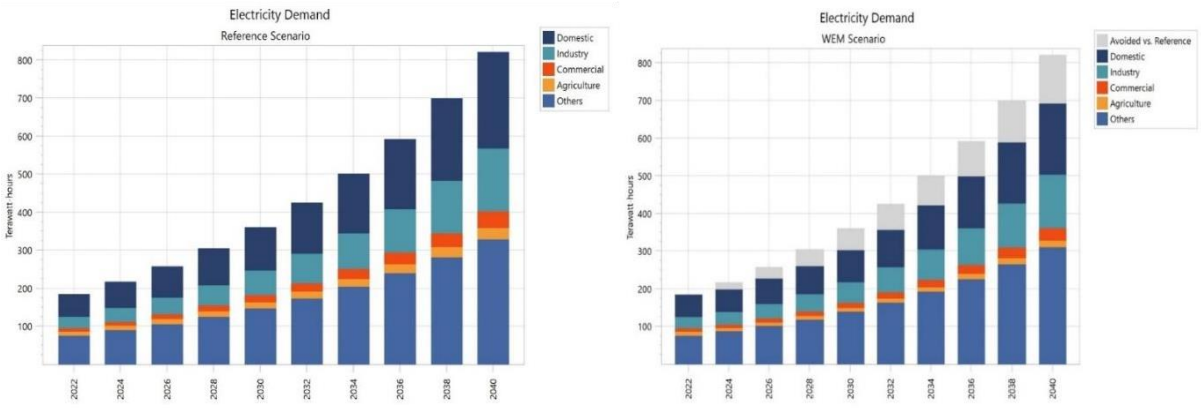

Figure 2. Electricity Demand from 2022 to 2040 under the reference and WEM Scenario

GHG Emissions in the Reference and WEM scenario

the reference scenario, energy production emissions rise from 78.7 million tons in 2022 to a projected 345 million tons in 2040, driven by increased coal-based electricity generation. The WEM scenario forecasts a 22.74% reduction in GHG emissions by 2030 and a 16.23% reduction by 2040, totaling 289.1 million tons, attributed to existing low-carbon technologies.

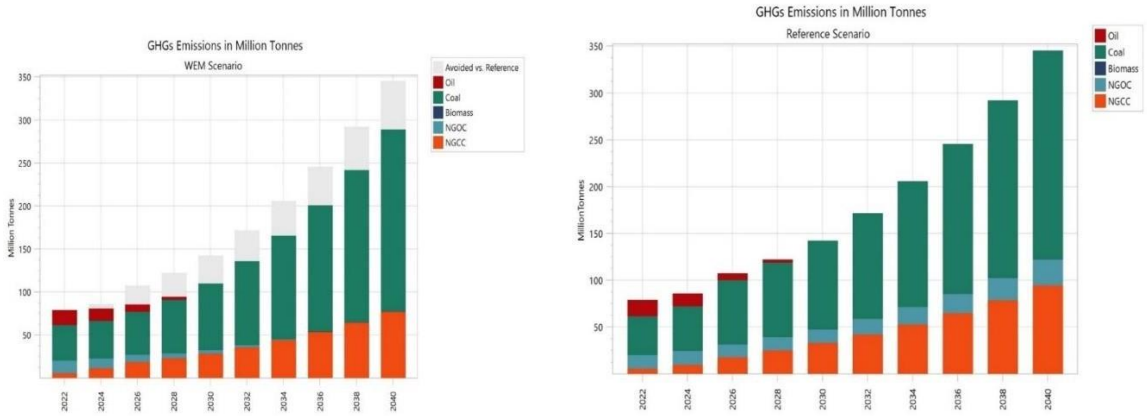

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Figure 3. GHG emissions in million tons from 2022 to 2040 under the reference & WEM scenario

Table 3. GHG emissions in million tons from 2022 to 2040 under the reference Scenario

Branch	**2022**	**2024**	**2026**	**2028**	**2030**	**2032**	**2034**	**2036**	**2038**	**2040**
Oil	16.9	13.3	6.9	3.1	-	-	-	-	-	-
Coal	41.6	47.4	68.5	79.5	94.1	112.5	134.0	159.3	189.0	222.8
Biomass	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3
NGOC	14.5	15.3	13.8	13.9	14.9	16.5	18.5	21.1	24.1	27.5
NGCC	5.7	9.7	18.1	25.4	33.3	42.4	52.8	64.8	78.8	94.7
Total	**78.7**	**85.7**	**107.3**	**122.0**	**142.4**	**171.6**	**205.6**	**245.4**	**292.2**	**345.3**

GHG Emissions in the WAM scenario

In the WAM scenario, renewable energy technologies contribute to a substantial CO2 emissions reduction, achieving net-zero emissions with around 80% generation from renewables. By 2040, energy generation is expected to produce zero emissions, reflecting a gradual decrease from 2022 due to renewable energy technology.

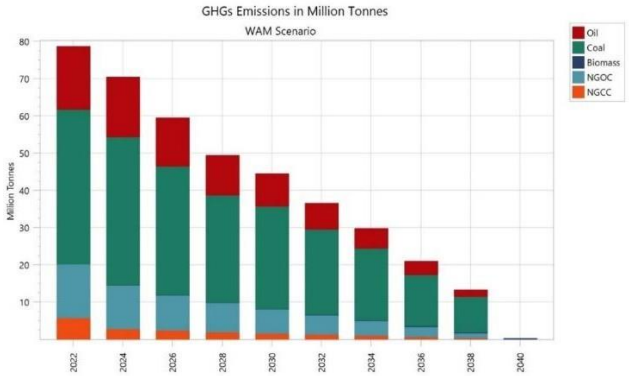

Figure 4. GHG emissions in million tons from 2022 to 2040 under the WAM scenario

Energy Security

This study defines energy security as diversified electricity generation capacity. A mix including renewables reduces vulnerability to fossil fuel disruptions. Adequate electrical capacity ensures a steady power supply, even with interruptions. Addressing factors like generation capacity and energy mix enhances energy security in developing countries like Pakistan.

Electricity Generation Capacity Mix under Reference and WEM

By 2040, Pakistan aims for 29.3% of electricity from renewables, boosting energy security. WEM scenario predicts 231.5 GW capacity, 73.2 GW less than REF, prioritizing efficiency, security, cost reduction, and renewables for sustainability.

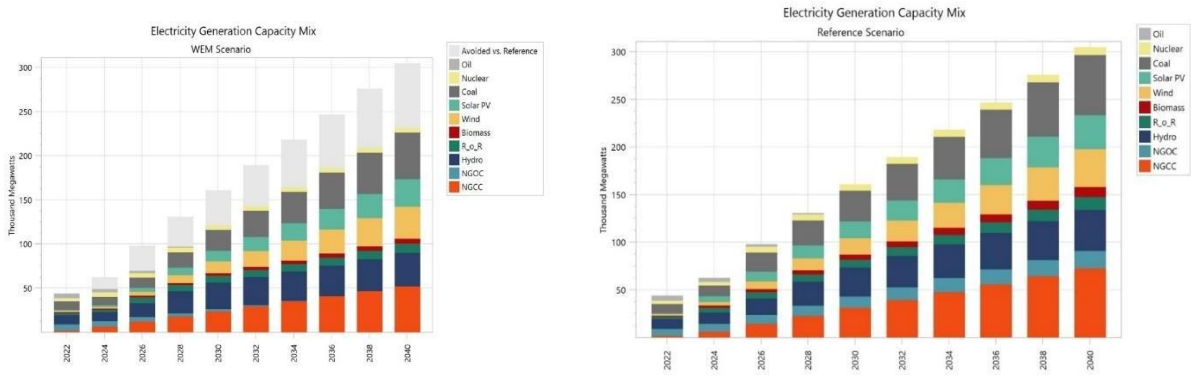

Figure 5. Electricity generation capacity mix from 2022 to 2040 under Reference & WEM scenario

Electricity Generation Capacity Mix in the WAM Scenario

WAM scenario sees a rise in total generation capacity (312.5 GW by 2040) with a substantial boost in solar (60.3 GW), wind (131 GW), and biomass (7.4 GW) capacities. Nearly 80% comes from renewables, ensuring energy security and emission reduction as shown in figure 6.

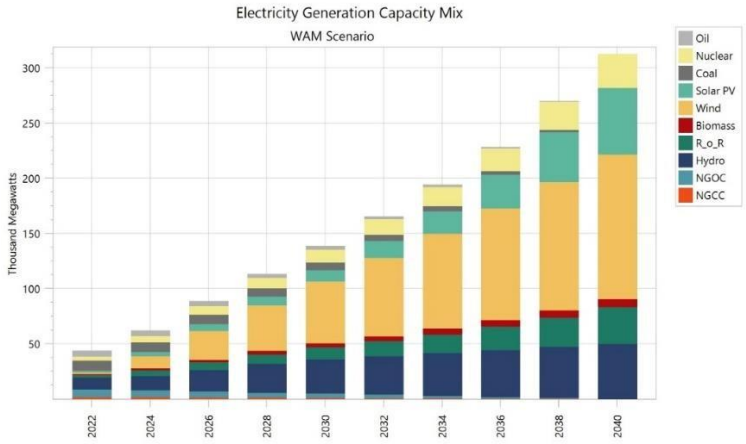

Figure 6. Electricity generation capacity mix from 2022 to 2040 WAM scenario

Energy Equity

This study uses electricity production cost as a proxy for energy equity, ensuring fair and affordable access for all. Incorporating renewable energy, though initially expensive, proves cost-effective in the long run, reducing energy poverty.

Electricity Production Cost under Reference & WEM Scenario

In the 2040 reference scenario, the total electricity production cost is US$66.3 billion, increasing over time. However, the WEM scenario, featuring energy-efficient technology, shows cost reductions: 14.8% less in capital costs, 14.9% less in fixed operation, and 24.2% less in variable operation costs, promoting energy equity through lower costs.

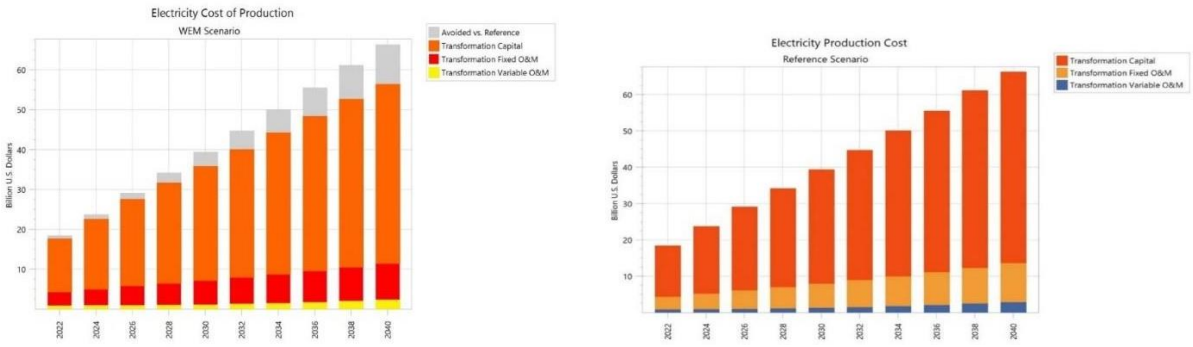

Figure 7. Electricity Production Cost from 2022 to 2040 under reference & WEM Scenario

Electricity Production Cost under WAM Scenario

In the WAM scenario, higher production costs are attributed to increased reliance on renewable energy technologies. Despite the higher costs, this intervention contributes to enhanced energy equity in the long

term, ensuring more reliable and widely accessible energy sources. This increased trend is shown is shown in figure 8.

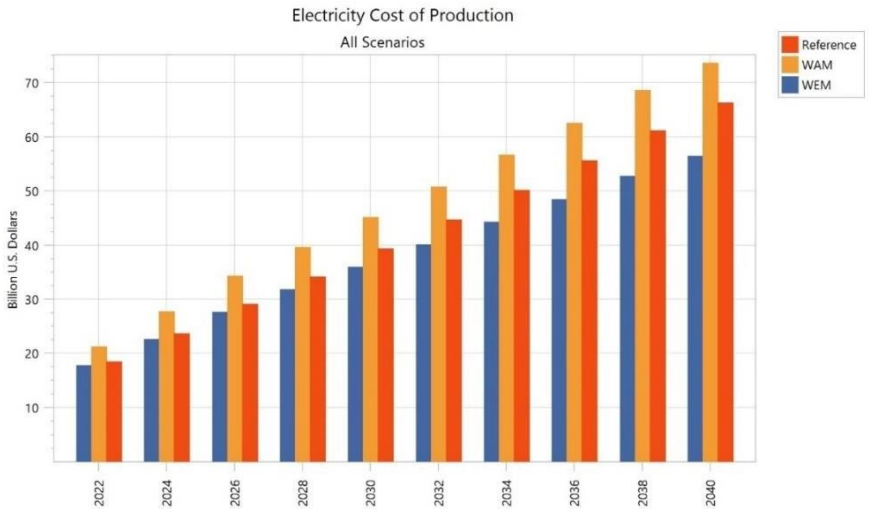

Figure 8. Electricity generation Cost from 2022 to 2040 under the WAM scenario

CONCLUSIONS

The main objective of the study was to create a framework for modeling energy in Pakistan with a focus on controlling emissions improving energy security and ensuring energy fairness. By examining the weaknesses in the energy structure and utilizing the LEAP model the study predicted three potential scenarios for the period between 2022 and 2040. The findings from this analysis offer insights, into how Pakistan's energy system could evolve in the future.

In 2040, greenhouse gas emissions from the energy production sector are estimated to be 345.3 million tons in the reference scenario, while the WEM scenario projects a reduction to 289.1 million tons, a 16.29% decrease, attributed to current technological policies promoting energy efficiency and low carbon technology. In the WAM scenario, achieving net-zero emissions is projected as emissions are significantly reduced, reaching zero by 2040. This is attributed to a substantial increase in renewable energy sources, constituting around 80% of the energy mix and reducing reliance on fossil fuels.

In 2040, the WEM scenario requires 73.2 GW less electricity generation capacity than the reference scenario, because of low-carbon technologies. The WAM scenario projects 312.5 GW total capacity by 2040, with 80% from renewables, boosting energy security and supporting net-zero emissions.

By the year 2040, according to the reference scenario the estimated cost of production is projected to reach $66.3 billion. However, through the implementation of energy methods, in the WEM scenario this cost can be reduced to $55 billion. On the hand, if we prioritize renewable technology in the WAM scenario it would result in a slightly higher cost of $73.6 billion. This approach aims to achieve long term energy equality by ensuring increased availability for all.

Recommendations

This research suggests that Pakistan should integrate decision support and energy modeling to ensure energy planning. The findings highlight the WEM scenario as a choice, due to its emphasis on energy efficiency, emission reduction, enhanced security and cost effectiveness. On the other hand, the WAM scenario, which

incorporates renewable technologies demonstrates the greatest potential for minimizing emissions. Although transitioning to renewables may involve costs, it promises long term benefits if done gradually, and equitable access to energy sources. It's worth noting that Pakistan has secured funding from the United Nations for projects aimed at reducing emissions. This underscores the importance of cooperation, in addressing climate change and promoting development.

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