Strategizing for Carbon Neutrality: Policy-Driven Insights Using LEAP for Pakistan's Energy Sector

sky news

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Why Carbon Neutrality for Pakistan?

Climate Vulnerability and Global Commitments

- Global Climate Risk Index
- Nationally Determined Contributions (NDCs)

Energy Security and Economic Stability

- Imported Fossil Fuels
- Transition to Indigenous, Renewable Sources
- Reducing Import Dependence
- Enhancing Resilience

Policy and Planning Gaps

- Lacks a Holistic, Data-driven Roadmap
- Quantitative, Policy-relevant Insights

Social and Developmental Co-benefits

- SDG 7 (Affordable and Clean Energy)
- SDG 13 (Climate Action)

Academic and Practical Relevance

- Replicable Framework
- Decision-support Tool

Research Motivation

- Severe Climate Vulnerability Threatens Pakistan’s Food and Water Security
- Energy Insecurity Fuelled by Dependence on Imported Fossil Fuels
- Net-Zero Targets Require Operational Pathways and Integrated Planning
- Fragmented Policies Undermine Long-Term Decarbonization Goals
- Low-Carbon Transition as a Catalyst for Green Jobs and Inclusive Growth

Research Gap

Research Gap	*Current study fills these gaps by:*
▪ Limited Net-Zero Pathway Analysis ▪ Energy Security Implications Under-Examined ▪ Equity and Access Largely Ignored ▪ Fragmented Sectoral and Policy Coverage	▪ Integrating measures across scenarios. ▪ Examining aggressive emission reduction strategies ▪ Linking renewable adoption to enhanced energy security. ▪ Explicitly addressing energy equity with efficiency and renewable expansions.

This work builds on prior literature but goes further to provide an integrated, policy-relevant roadmap where GHG mitigation, energy security, and energy equity goals are advanced in unison.

Research Objective

To assess greenhouse gas (GHG) reduction, energy security, and energy equity in Pakistan's power sector using the Low Emissions Analysis Platform (LEAP) over the period 2022–2040 under three policy-driven scenarios:

- Reference Scenario (REF): Business-as-usual pathway with continued reliance on fossil fuels.
- With Existing Measures (WEM): Incorporates energy-efficient technologies already under implementation.
- With Additional Measures (WAM): Integrates advanced renewable energy technologies targeting a net-zero trajectory.

Overview of LEAP

- LEAP (Low Emissions Analysis Platform) is a scenario-based energy-environment modeling tool developed by the Stockholm Environment Institute (SEI).
- It is designed to support long-term energy planning and climate mitigation analysis in both developing and developed contexts.

Core Features of LEAP:

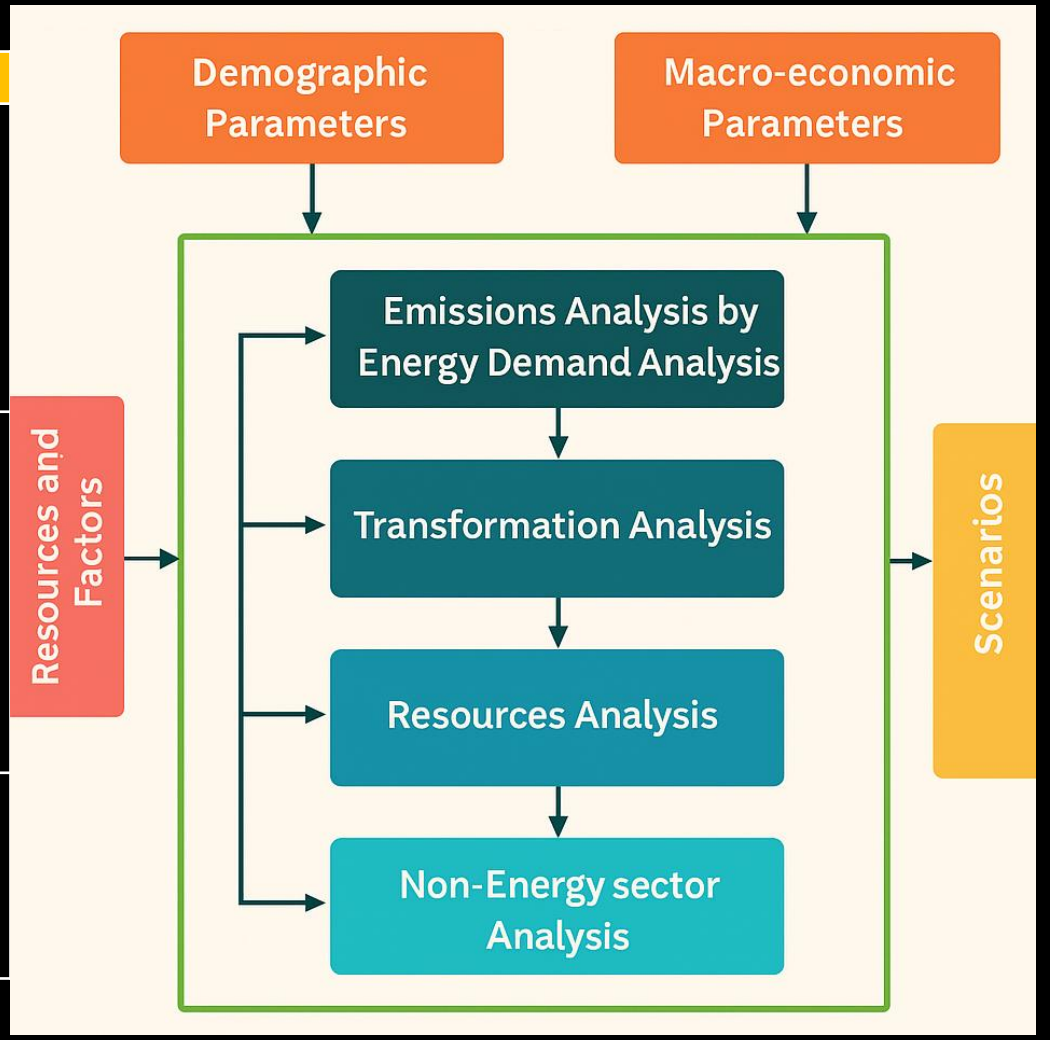
- Bottom-up Modeling: Captures sectoral details (households, industry, transport) with demand and supply modules.
- Scenario Analysis: Allows exploration of alternative policy pathways (e.g., REF, WEM, WAM).
- GHG Emissions Accounting: Compliant with IPCC 2006 Guidelines for energy-related emissions inventories.
- Integrated Cost Assessment: Estimates capital, fixed and variable O&M, and fuel costs.
- Energy Security & Equity Metrics: Tracks diversity of energy mix and affordability.

Model Architecture:

1.Demand Module: Disaggregates energy use by sector and end-use.
2.Transformation Module: Models power generation, T&D losses, and efficiencies.
3.Resources Module: Captures primary energy availability (e.g., coal, gas, renewables).
4.Environment Module: Calculates emissions of CO_2, CH_4, N_2O, etc.

Methodological Framework

Component	Description	Purpose/Outcome
Energy Modeling and Projections	Used LEAP to project energy demand, capacity, generation, cost, and emissions from 2022 to 2040 under the Reference Scenario.	Establishes the baseline trajectory for Pakistan's energy system.
Policy Intervention Scenarios	Developed two alternative policy pathways:	Explores the effect of policy measures on emissions and energy performance.
	WEM: Integrates energy-efficient technologies.	
	WAM: Emphasizes renewable energy adoption for net-zero target.	
Comparative Analysis	Assessed the environmental, economic, and energy security impacts of REF, WEM, and WAM scenarios.	Evaluates trade-offs and co-benefits to inform policy decisions.



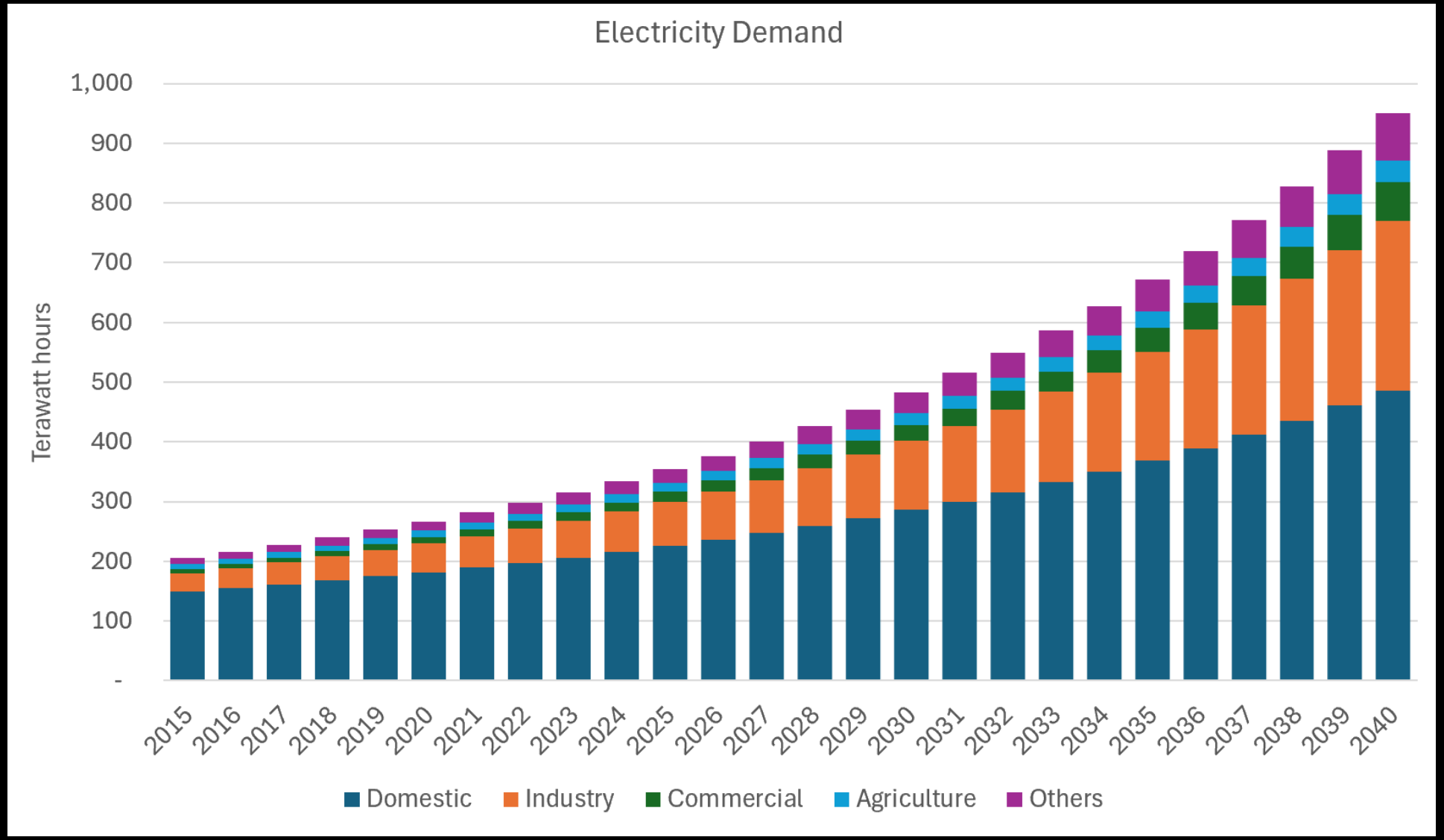
Key Assumptions

Parameter	Base Year (2022)	Unit	Growth Rate / Source
Population	235.8 million	People	1.7% annually (Pakistan Economic Survey, 2022)
Households	34.5 million	Number of households	Derived from population and household size
Household Size	6.3	Persons/household	Constant
GDP	362.6 billion USD	Gross Domestic Product	6% annual growth
Income per Capita	2,000 USD	USD/person	6% annual growth
Energy Demand	184 TWh	Electricity (TWh)	Projected with economic and demographic trends
Emission Factors	-	IPCC-compliant units	2006 IPCC Guidelines

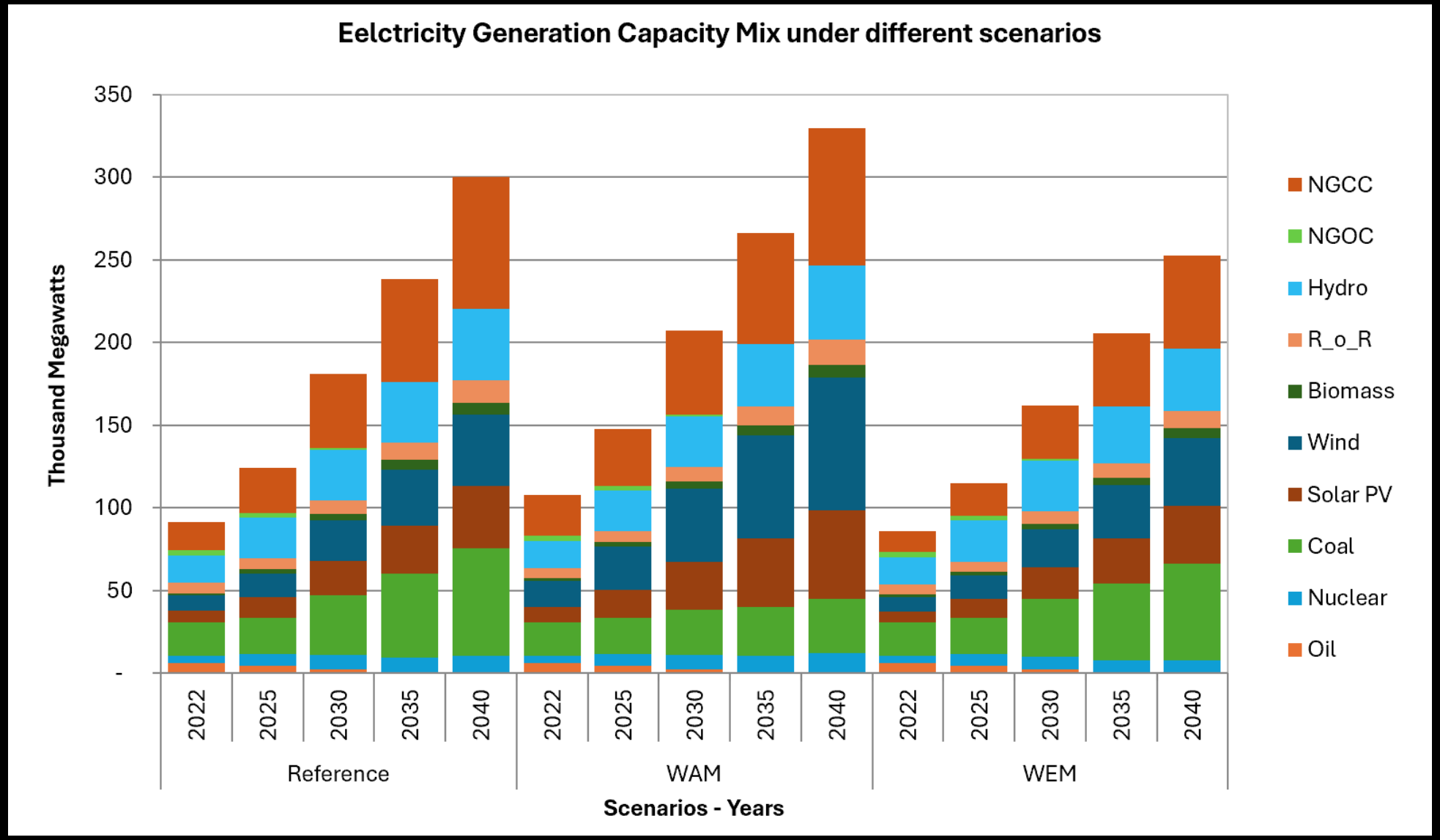
Scenario Overview

Scenario	Acronym	Core Assumptions	Emissions Trajectory	Energy Mix (2040)
Reference Scenario	REF	Business-as-usual (BAU); no new interventions; continued reliance on fossil fuels.	Increases from 78.7 Mt to 345.3 Mt CO_2-eq.	Fossil-dominated; low renewable share.
With Existing Measures	WEM	Includes current energy efficiency policies and technologies.	16.23% lower than REF (289.1 Mt by 2040).	Renewables: ~29.3%; Improved efficiency.
With Additional Measures	WAM	Emphasizes large-scale integration of renewables (solar, wind, biomass).	Net-zero emissions by 2040.	Renewables: ~80% of generation capacity.

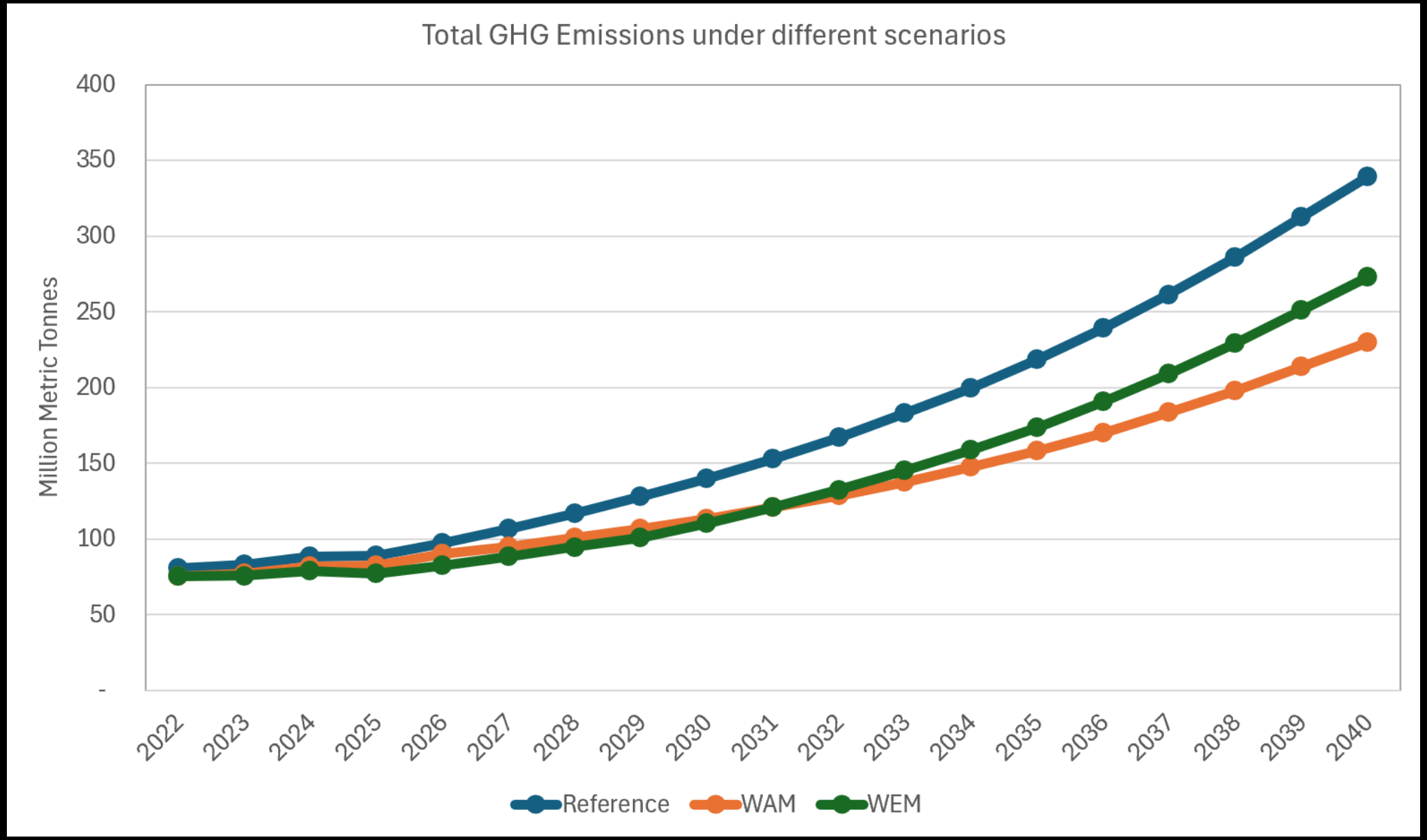
Electricity Demand Growth



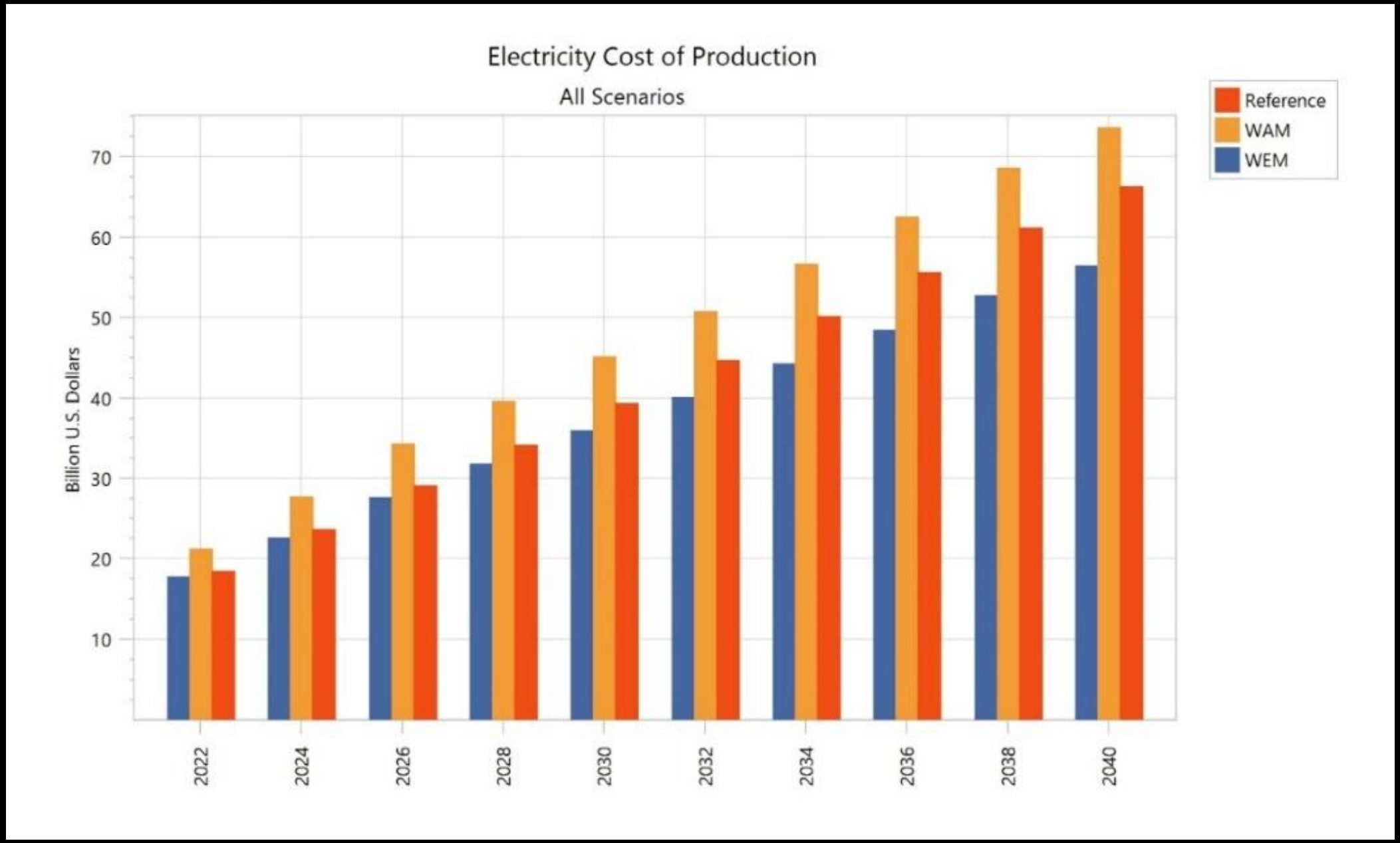
Generation Capacity Mix



GHG Emissions Trajectory



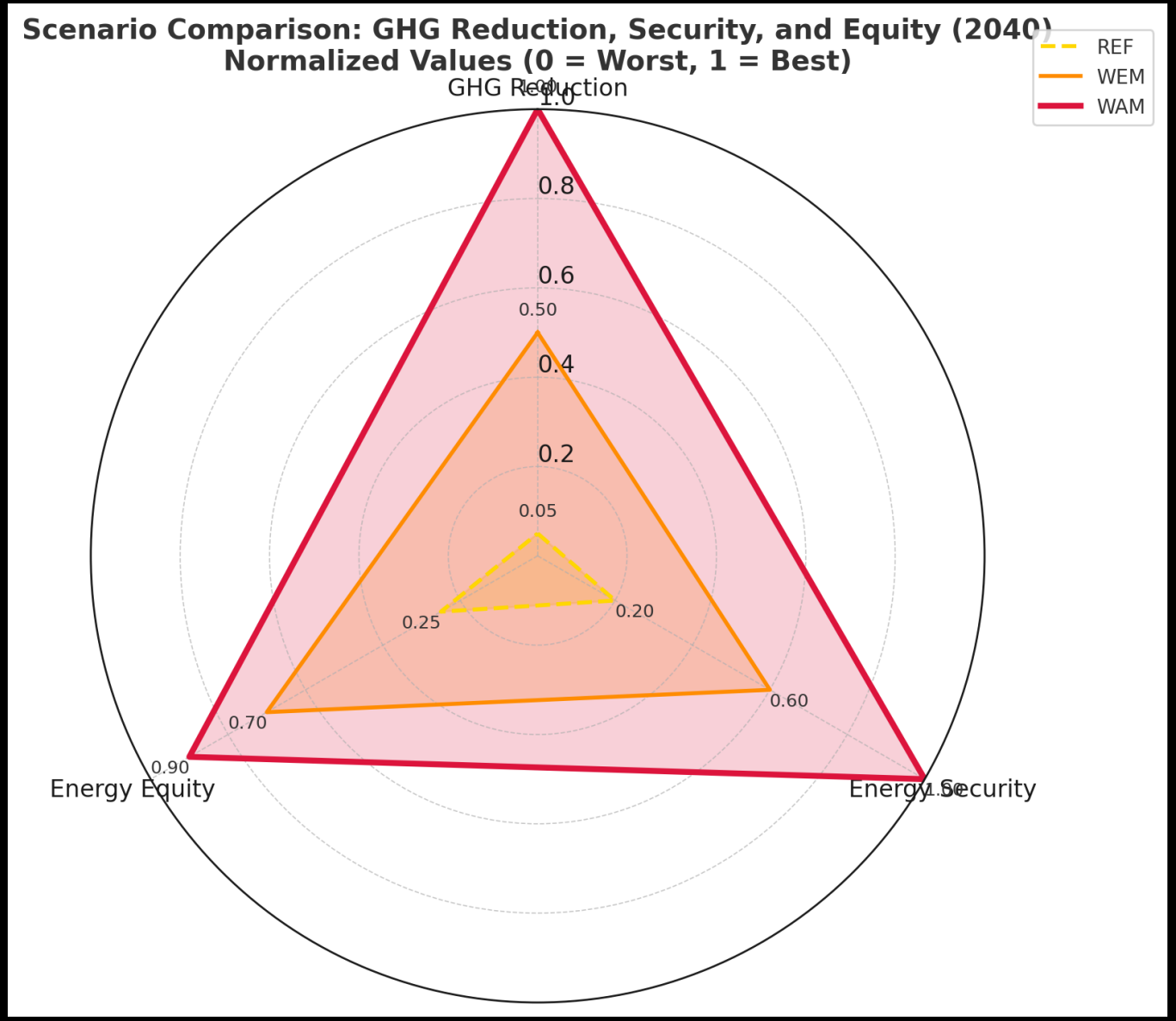
Electricity Generation Cost



Summary of Results

Indicator	Reference (REF)	With Existing Measures (WEM)	With Additional Measures (WAM)
GHG Emissions (Mt CO_2-eq)	345.3	289.1 (↓16.29%)	230 (↓)
Energy Mix	Fossil-dominated	Renewables: ~29.3%	Renewables: ~80%
Installed Capacity (GW)	304.7	231.5 (↓73.2 GW from REF)	312.5 (↑ due to renewables)
Electricity Production Cost	US$66.3 billion	US$55 billion (↓ cost due to efficiency)	US$73.6 billion (↑ capex, long-term equity gains)
Energy Security	Vulnerable to fossil fuel price and supply risk	Improved via reduced demand and diversified sources	Significantly enhanced via renewable dominance
Energy Equity	Lower access & affordability for low-income	Improved via cost savings and demand reduction	High long-term equity via cleaner, accessible energy

Conclusions



POLICY RECOMMENDATIONS

Strategic Energy Planning
Institutionalize decision support systems and energy-environment modeling (e.g., LEAP) in national planning.

Energy Efficiency
Prioritize WEM scenario measures such as low-carbon technologies, efficient appliances, and demand-side management.

Renewable Integration
Adopt a phased approach to WAM:
Start with scalable renewables (solar, wind) while managing capital cost barriers.

Equity & Affordability
Promote energy equity through targeted subsidies, off-grid renewable solutions, and affordability-focused planning.

International Cooperation
Leverage UN and multilateral climate funds to support clean energy transitions and technology transfer.

Thank You

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