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Study Of Factors Impacting Energy Security And Implications For Developing Countries

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Abstract: This study has been undertaken to understand factors that impact energy security and how energy security is measured. Furthermore, the study investigates if there is co-relation between income levels and energy security. Finally looks at case studies of developing countries in improving energy security to see what the learnings are.

Index Terms – Energy security, trilemma index, energy security for developing countries, energy security measurement.

I. INTRODUCTION

The United Nations defines energy security as "continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices" which means having access to diverse sources of energy in a reliable and affordable manner.

Key dimensions of energy security are

- Availability: Sufficient supply of natural resources to generate energy e.g., fossil fuels, hydel, wind etc.
- Affordability: Availability of energy at a reasonable price to be able to be used by people
- Access: Having the infrastructure to be able to supply energy in an affordable manner
- Sustainability: Managing and mitigating long term environmental impact through efficiency improvement and moving towards renewable and less polluting sources

Energy security is critical for a number of reasons- a) Energy security helps in the process of industrialization as industries rely on reliable and affordable energy, b) Social development needs energy security to power schools, hospitals etc., c) Infrastructure development like roads, ports etc. needs energy security, d) Reliance on expensive imported energy can make a country vulnerable to price fluctuations, trade imbalances, and energy supply disruptions, impacting both economic stability and national security.

Given the criticality of energy security on socio-economic development, this research paper looks to examine how energy security is measured, contrasting analysis of energy security status between developing and developed countries and finally a deep dive into the Indian energy security situation to finally conclude with learnings and suggestions on achieving energy security.

II. MEASUREMENT OF ENERGY SECURITY

There are four generally accepted dimensions of energy security: Availability, access, affordability and sustainability. Therefore, measurement of energy security incorporates all of the above dimensions. Within each of the dimensions there can be multiple parameters that impact it. Each of these parameters can be estimated using multiple indicators. The table below helps us understand these parameters and an illustrative set of indicators that can be used for these measurements

Table 1: Factors impacting energy security

Dimension	Parameters	Illustrative Indicators
Availability	**Geological:** Availability and distribution of resources **Techno-commercial:** Infrastructure/know how and capital to utilize resources **Political and geo-political:** Dependence on unstable supply, policy support **Environmental:** Ecological issues, resource depletion,resultant pollution, climate impact on wind/hydro energy **Social:** Support or opposition of communities for setting up power plants/facilities	● % of energy imported ● Oil or coal production per capita ● Size of known oil reserves per capita
Access	**Income levels:** Ability to buy energy given energy prices. Lower income level can lead to lower access **Infrastructure and connectivity:** Extent and reliability of power grid, road/rail networks, availability of oil/gas pipelines **Policy and Governance:** Government programs, policy framework for private sector participation, promoting investment in energy **Geographical factors:** Mountainous terrain, island communities etc. it is difficult and relatively expensive to provide energy access **Social and Equity factors:** Disadvantaged households, sparsely populated communities etc. can have access challenges **Technological innovations:** Innovations in energy transmission and storage etc.	- % population with electricity supply - Km of HT lines in a country - Km of oil and gas pipeline in a country
Affordability	**Global energy markets:** Energy demand supply and global energy prices **Geo-political factors:** Import dependency and relationship energy exporters **Policy:** Taxes, levies, subsidies etc. **Usage efficiency:** Energy wastage by end users, transmission losses **Mix of energy source:** Dependence on cheaper sources like wind or solar vs dependence on oil/coal based energy	- Electricity prices - Gasoline and Diesel prices
Sustainability	**Mix of energy source:** Dependence on fossil fuels which cause emissions leading to pollution and also consume lot of water vs having a higher share of renewable sources **Energy efficiency:** Technological innovations and good practices that can help improve distribution and usage efficiencies have are good for sustainability **Demand management:** Incentivizing users to limit peak time usage though tariffs and other means can lead to a more sustainable energy situation **Grid planning:** Grid planning allowing for multiple uptake points for renewable sources like solar and wind	- % energy generation from renewable sources - CO2 emissions per capita

	can help improve contribution or renewable sources and improve sustainability Policy:	

Given the complex set of factors that impact the key dimensions of energy security, measurement of energy security is not straightforward. Various agencies like the World Energy Council (WEC), International Energy Agency (IEA) etc. have devised indices to measure energy security. While there are different frameworks there are also some common themes in these frameworks

1) Most indices break down energy security into factors impacting it e.g., supply risk, infrastructure reliability etc.
2) There are both negative and positive factors, indices take care of them by subtracting or adding
3) To make comparison across countries possible factors are normalized
4) Weights are assigned to factors within a dimension to finally arrive at a dimension level score

Below table lists out some of the energy security indices that are in use

Table 2: Energy security indices

Agency	Index	Description
International Energy agency (IEA)	MOSES (Model of short term energy security)	MOSES is a tool to inform energy-security policies through quantifying vulnerabilities of energy systems. It is based on a set of quantitative indicators that measures two aspects of energy security: - Risk of energy supply disruption - Resilience or ability of a national system to cope with such disruption - Look at both domestic and external measures for risk and resilience. Overall 29 measures used to construct the profile - Countries are not ranked but energy security profile is generated and they are grouped in five groups from A to E
World Energy Council (WEC)	Trilemma Index	Benchmarking of national energy systems on - Security: import dependence, diversity of generation, storage capacity - Equity: Access to electricity, electricity prices, gasoline and diesel prices - Sustainability: Energy intensity, low carbon generation and CO2 emissions - Has individual scores for above and an overall index score called Trilemma Index - Countries are ranked based on overall Index score - Covers over 100 countries
LUT University (Azzuni and Breyer)	Global Energy Security Index	- Detailed numerical method to formulate an energy security index that is globally comprehensive, but also nationally applicable to all countries in the world - Considers 15 dimensions: Availability, Diversity, Cost, Technology and Efficiency, Location, Timeframe, Resilience, Environment, Health, Culture, Literacy, Employment, Policy, Military and Cyber Security - For each dimension, parameters are assigned, measured or calculated indicators. Then, all values are normalised and standardised to a percentage value

		- These percentages for each parameter are then multiplied by their weights - Overall 15 dimensions, 50 parameters and 78 indicators
Regional: Global energy institute, US Index	Index of U.S. Energy Security Risk	- Focused on U.S. energy security risks: historical +forecast; measuring vulnerabilities in global energy markets, dependence, volatility, policy risks etc - Uses about 37 metrics grouped into 9 categories
Regional: USAID/Aid Data	Europe & Eurasia Energy Security Index	Constructs an index measuring multiple facets of energy security. (Exact indicators vary by country & data availability.) Likely includes import dependence, supply diversity, resilience of infrastructure, maybe governance or institutional capacity. Data is compiled annually to track trends.

III. Analysis of energy security status across countries: Energy security score vs GDP

In this section of the research there is an attempt to correlate the 2023 Trilemma index score and its three constituents (energy security score, energy equity score and environmental sustainability score) to per capita GDP (2023 current prices) to see if energy security is correlated with income levels.

Figure 1: 2023, Trilemma score vs per capita GDP

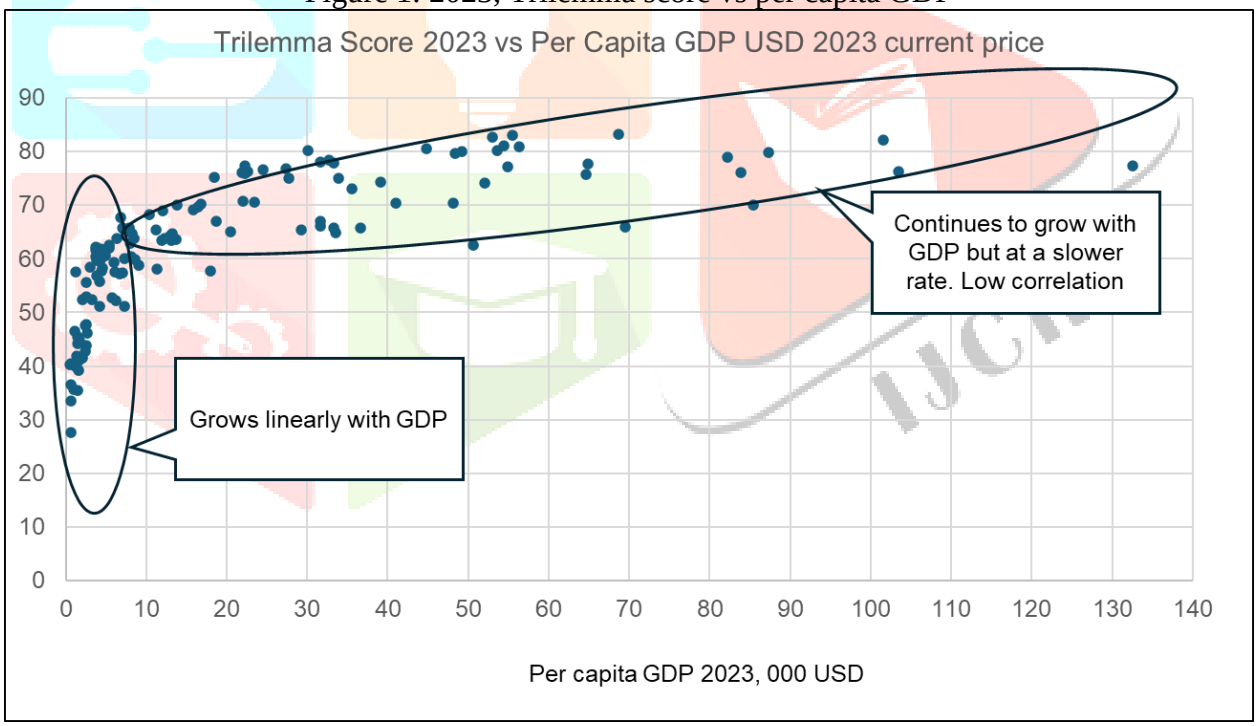


Figure 2: 2023, Energy security score vs per capita GDP

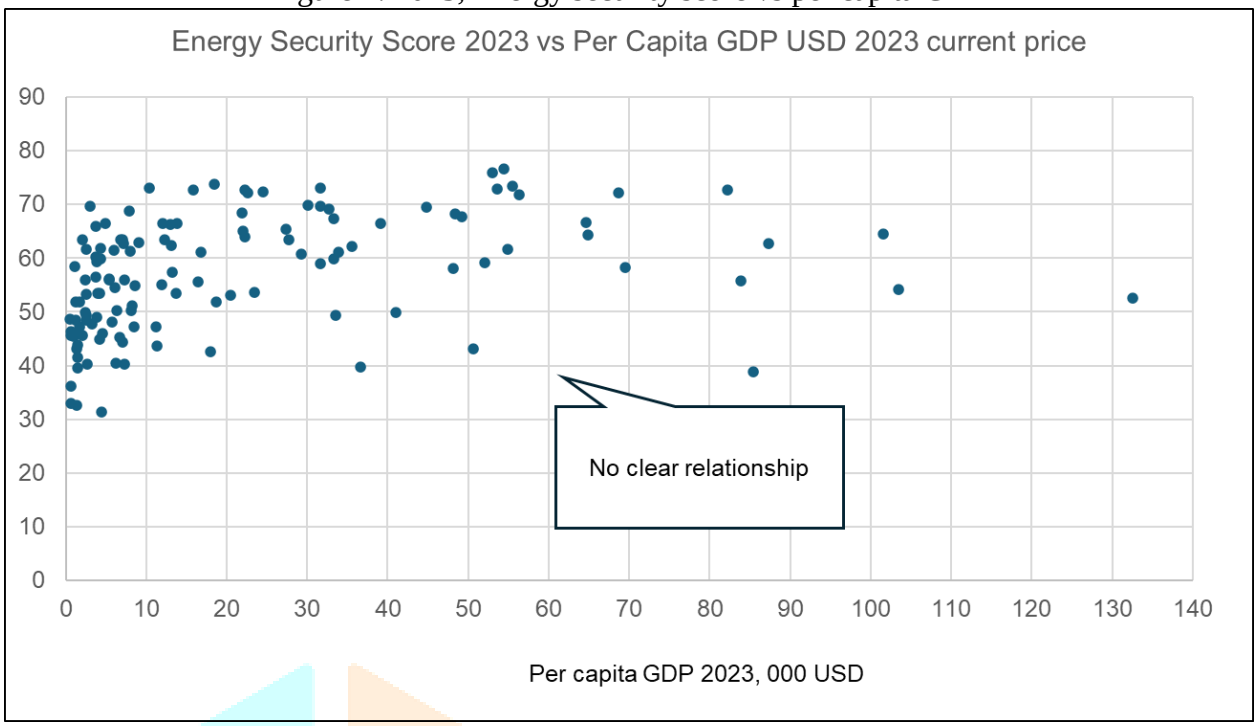


Figure 3: 2023, Energy equity score vs per capita GDP

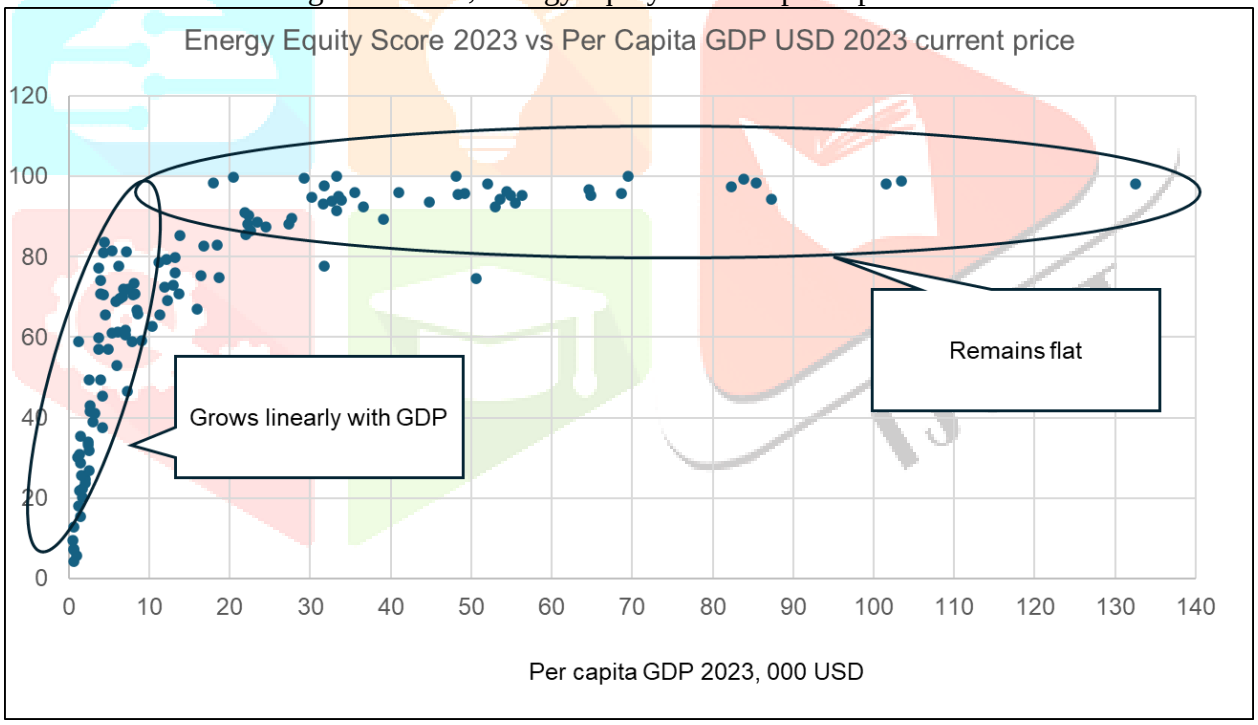
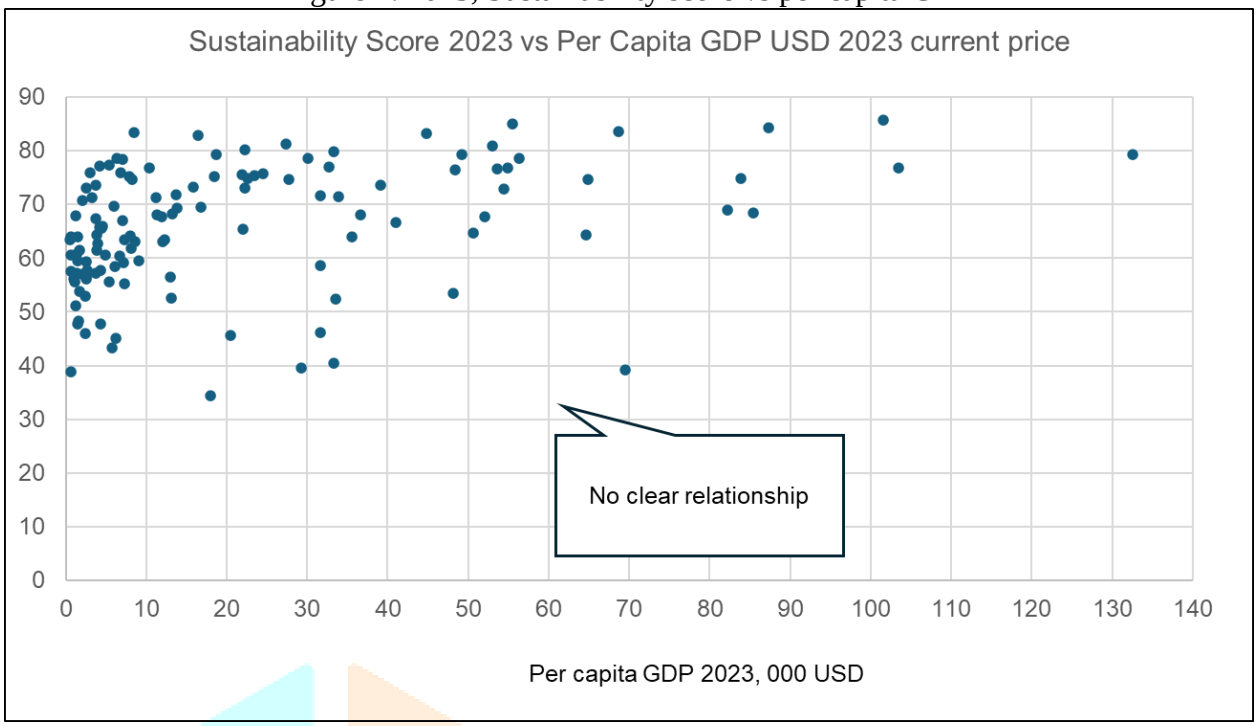


Figure 4: 2023, Sustainability score vs per capita GDP



Inferences:

Looking at figures 1 to 4 we can draw the following inferences. There is a rapid improvement in the Trilemma index as per capita income levels increase from 0 to 7500 USD per capita and rate of growth is almost linear. Above 7500 USD per capita, the improvement in Trilemma index slows down considerably. Looking at figures 2 to 4, which are constituents of the Trilemma index score we can see that growth mentioned in the previous point is largely on account of the energy equity score which grows rapidly with improving incomes till around 7500 USD per capita post which it flattens out. There is no clear co-relation of energy security scores or sustainability scores with income levels (per capita GDP), however it may be observed that countries with higher incomes have better security and sustainability scores. This can be observed by looking at table 3 below

Table 3: Average Trilemma scores by income buckets

Per Capita GDP bucket, 2023 current price	**Average Trilemma Score**	**Average energy security score**	**Average energy equity score**	**Average sustainability score**
< 7500	51.5	50.8	45.6	61.1
7500 to 15000	63.9	58.4	71.0	67.2
15000 to 30000	71.9	63.2	87.2	69.6
> 30000	75.2	62.5	94.6	70.4

IV. Case Studies

In this section Uruguay and India case studies are presented. Uruguay, a developing country which has done a great job at securing its energy security and has among the highest trilemma scores among developing countries at ~ 75.9. India which has been one of the fastest growing economies in the world and has a huge energy requirement. While its per capita GDP is not very high and it also has a high import dependence, it has been able to get to energy security index of 55.6.

Uruguay

Uruguay ranks among the best in developing nations when it comes to energy security. It is ranked 21 overall in the Trilemma index. It does not score very high (in relative terms) on energy security, it scores high on energy equity and sustainability.

Uruguay's political stability and strategic energy policies have significantly supported its leadership position. It was a mix of multiple government policies along with advantageous geography which allowed Uruguay to reach this position in electricity. Key decisions, such as a 2008 multi-party agreement establishing the long-term national energy strategy for decarbonizing electricity generation, played a crucial role in this. Since 2008, Uruguay has become a global leader in renewable energy thanks to deliberate government policies. The country adopted long-term energy plans that encouraged public–private partnerships, guaranteed stable contracts for investors, and diversified its energy mix beyond hydropower. Massive investments were made in wind and solar power, supported by strong state incentives and clear regulatory frameworks. By 2015, these policies had allowed Uruguay to generate over 90% of its electricity from renewables, while reducing dependence on imported fossil fuels. Current estimates suggest that over 98% of energy in Uruguay is from renewable sources.

The situation was not always like this, in the early 2000s, Uruguay imported nearly all its oil and oil products, and electricity from Argentina, which led to vulnerability and economic strain. While hydropower was traditional, a decade of dry years (1997-2007) severely reduced its contribution, forcing increased reliance on expensive imported fossil fuels.High oil prices and import costs created a fiscal burden and economic vulnerability for the nation. In 2005, Uruguay launched an aggressive energy strategy to transition away from fossil fuels and increase the share of renewable energy.

Uruguay also excels in energy equity, mainly thanks to its near-universal electricity access across the country (more than 99% of the population in the past 15 years). In 2021 the Government utility power company (UTE) implemented the program "Uruguay 100% Electrificado" to ensure 100% electricity access in rural areas. In addition, as of 2024, UTE has installed smart meters for 100% of its consumers, enabling an accurate electricity consumption measure and empowering Uruguayans through the understanding of their electricity use.

India

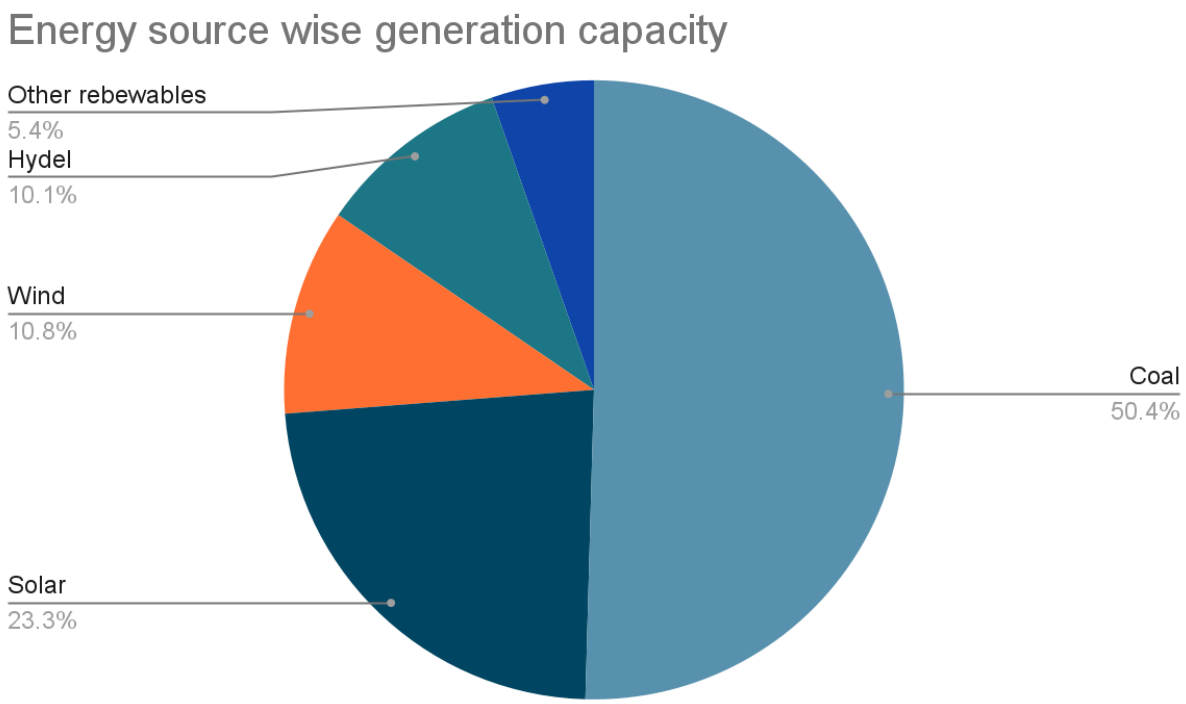
India is the world's 4th largest economy and also one of the fastest growing large economies of the world. It is also the world's third largest energy consumer with a rapidly increasing energy demand to fuel economic growth and development. While in absolute terms it is third highest, in per capita terms it is one third of global average and not even among the top 100 countries. Therefore securing energy security is of critical importance for India to be able to secure its ever increasing energy needs in an equitable and sustainable manner. India had an overall score of 55.6 and a rank of 74 in the 2023 World Energy Trilemma Index. The country scored 61.7 in Energy Security, 49.5 in Energy Equity, and 56.5 in Environmental Sustainability.

Over the last two decades India has made good improvements towards securing energy security for its growing economy and population. India had a trilemma rank of 115 in 2015 which has improved to 74th in 2023 and 2024. Its journey over the last 2 decades has seen a strategic pivot from fossil fuel dependency towards renewables combined with initiatives to improve access and affordability. It is an interesting case study of balancing act to meet demand while managing import vulnerability and climate commitments.

The most important aspects of India's journey has been diversification with capacity and access improvement.

Diversification: There has been a rapid scaling of renewable sources. Total non fossil fuels based capacity now accounts for ~ 50% of India's generation capacity out of a total of 476 GWB

Figure 5: India power generation capacity by source, 2025



This was not the case 10 years ago. Non-coal capacity which was at 76 GW increased to 243 GW (2015 to 1025) whereas coal based capacity grew from 229 GW to 240 GW, only a marginal increase. In the same period solar increased from 2.5 GW to 120 GW, a whopping 40-fold increase.

This has been possible through strong government commitment, favourable policies, technological advancements and private sector participation. India has set a 500 GW renewables target by 2030. There are supporting schemes and incentives like renewables purchase obligation, viability gap funding and production linked incentives. Waiver of iter state transmission charges for renewables also helps. On the technology side the set up cost has been going down with advancements in battery storage systems and smart grid technologies have helped in integration.

India has also worked on improving energy access to make it more equitable. It is estimated that 100% of Indian villages were electrified by 2018 with ~ 28 million households connected. Efforts are on to ensure further coverage of households and ensure reliable supply of electricity. Some notable welfare schemes in this direction are

- Universal electrification through Pradhan Mantri Sahaj Bijli Har Ghar Yojna
- Clean cooking fuel through Pradhan Mantri Ujjwala Yojna

Despite the progress made many challenges still remain

- Import dependency for crude oil continues to be a challenge for India, India being one of the largest importers of crude (over 80% of requirement)
- Coal continues to account for a very large % of installed generation capacity raising environmental concerns
- Solar and wind which are largest contributor to Indian renewables have inherent fluctuations which need storage and technology solutions for mitigation
- India has one of the highest rates of transmission and distribution losses and this remains a challenge due to technical inefficiencies and thefts.

V. CONCLUSION

In conclusion it can be said that

Energy security has multiple dimensions and it depends on multiple factors. Measuring energy security is not straightforward, but indices have been devised which measure and track it. Energy security seems to improve with improving income levels, particularly the equity and access of energy.

In terms of implications for developing countries, the most important one is on the role of government in ensuring energy security (as we can see from the two case studies). The government has an important and multifaceted role to play here through

- Diversification of energy sources
- Promoting domestic sources
- Direct investments and viability gap investments
- Creating a conducive policy framework with correct investments promotion, incentives and market regulation
- Efficient supply and demand management
- International co-operation and technology transfer

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