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Adaptive Energy Management In Carbon-Constrained Future: The Role Of Energy Policy In South Africa

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Abstract– The role of energy policy in South Africa cannot be underestimated particularly in providing strategic direction and vision to ensure energy development and energy security in a continued carbon constrained future. These policies, strategies and frameworks pursuit sustainability, reliability and economic growth. In essence, there is a need for just energy transition from fossil fuel consumption to renewable energy sources to mitigate environmental pollution and climate change. Just energy transition has a potential role in providing clean energy, creation of local jobs and economic growth. In addition, it also encourages private sector participation in energy developments. Therefore, energy policies have the potential to shape and achieve economic growth, industrial growth and to create decent and sustainable investments while mitigating carbon dioxide emissions. In contrast, policies, and frameworks like Energy Act 04 of 2004, Integrated Energy Plan (IEP), National Development Plan (NDP), Renewable Energy Independent Power Producers Programs (REIPPPP) have played an important role in fostering energy access and energy security. The study methodology used to collect data was through mixed research approach by using qualitative, quantitative research and statistical data analysis. The results show that energy policies have significantly contributed to the rollout of renewables and energy storage. Furthermore, through REIPPPP project Bid (Windows 1 to 4), more than USD 14 billion has been invested by private public partnership which has increased local job creation and reduction in carbon emission. On the contrary, power utility is unable to meet environmental compliance by reducing Sulphur dioxide to acceptable limits and thus poses a risk of 22 GW capacity shutdown by 2030.
Keywords– Energy Policies, Renewable Energy, Adaptive Energy Management, Decarbonization.

I. INTRODUCTION

As the renewable energy sources are increasingly penetrating to the grid, energy policies, impact on the grid operation, energy management, maintenance and reliability is becoming far more important to understand [1]. In contrast, energy values chain is affected by various factors which include sustainability, strategies, framework, and energy policies. To address these and other factors, such as energy security, energy access, energy cost, management of assets and evaluation of energy policies adaptive energy management is crucial to consider. Meanwhile, power utility continues to experience challenges of environmental compliance due to flue gases such as carbon dioxide, Sulphur dioxide and nitrogen oxide to an acceptable level. This has been a challenge and burden which requires huge amount of money estimated to approximately USD 14,4 billion to achieve full compliance across its coal fired fleet [2].

Equally, access to sustainable, affordable and reliable energy is the key objective of developing countries to improve social and economic developments. In short, government should produce strong energy policies that promotes renewable energy for economic growth and increasingly attract foreign investments [3]. Currently, South African government have developed key energy policies, for example White Paper on Renewable energy policy, Energy planning, Electricity Act, REIPPPP which pledges for government support for the development, demonstration and implementation of renewable energy sources for both small and large scale application. As a result, these policies outline the government vision, strategic goals, and objectives for promoting and implementation renewable energy in South Africa. National Energy Regulator of South Africa (NERSA), Eskom and South African Parliament and Legislature, Department of Mineral Resources and Energy (DMRE), Department of Energy (DOE) are some of the bodies responsible for developing frameworks, procedures, policies and energy strategies responsible for unlocking and fostering inclusive developments in energy value chain. Therefore, the role of these governmental departments is to set minimum and acceptable standards, strategies and policy framework

for the development of energy value chain and utility grid integration to achieve sustainability and energy security [4].

The aim of this study is to develop knowledge of the impact of energy policies in shaping the success of energy transition through adaptive energy management and planning. The objectives are to further investigate the effectiveness of maintenance strategies applicable to boiler plant with an attempt to improve the reliability of the boiler plant. The specific research objectives are:

i. The role of energy policies in unlocking investment opportunities.
ii. The benefits of renewable energy and energy storage roll-out

The contribution of this study to provide the understand of the role and impact of energy policy in South Africa, monitor and control the implementation of energy policy framework, encourage transparency in public and private sector participation in policy developments. Most importantly to provide an insight in the role up to this far played policy framework in harnessing developments in renewables, job creation and economic growth.

The structure of this paper is as follows, Section II review the literature study of energy strategy and policy framework; Section III analyses and discussion of energy developments in South Africa and Section IV presents the conclusion and recommendations of the study.

II. LITERATURE REVIEW

Renewable energy transition is a process of rapid exploration of renewable energy technologies in electrical grids and technological shift from traditional fossil fuels to a cleaner, economic, and reliable energy for the benefit of society. Today, energy sectors across the globe have witnessed an increase in renewable developments because of its simplicity and performance. It emerges [5] that energy transition needs to consider and address factors such as affordability, efficiency, reliability and energy independence. On the other hand, energy transition must involve social inclusion, economic development and environmental sustainability as the key pillars of energy in developing countries.

In South Africa, the objective of energy transition among others is to reduce greenhouse gas emission while providing sustainable energy. The framework, energy policies and strategies have been set aside for reducing emissions to an acceptable limit. In correlation, South Africa is the largest contributor to global emission due to mostly coal fired power generating plants and it has been a challenge to meet environmental compliance. To mitigate continuous air pollution [6] suggests that a transition from coal fired power plants to renewable energies will enable to reduce carbon emission by 8% in 2050 compared to 2015. It is noted however that the author does not provide a detailed analysis of how this reduction will be achieved. Additionally, the author makes assertion of achieving a reduction of 8% by fully transitioning to renewables by 2050, which is not practicable since the economy highly depends on the effective operation of coal power plants.

Energy transition needs to be utilized as a driving force for social economic needs in developing countries. In his article, [7] presents that energy transition has potential for economic development, investments and job creation. The author developed a case study to evaluate complete energy transition in Spain with the aim of economic growth. The study then concludes that transitioning from coal and nuclear in 47 regions in Spain can improve job creation of about 500k. It is, however, noted that the author does not propose any strategy to achieve this energy transition. Despite the anticipated growth of job creation and economy, strong, reliable and measurable energy policies should be developed as a driving force behind energy transition.

The environmental impact of air pollution in South Africa due to fossil fuel, increased carbon monoxide and other factors has resulted in severe climate changes [8]. The study reflects on environmental disasters across the globe with an objective of mitigating its social and economic impact. The author referred to devastating floods occurred in South Africa, Kwa-Zulu Natal Province in April 2022. The study suggests that due to these floods because of climate change more than 500 lives were lost, 12 000 homes destroyed and infrastructure like water and sanitation, power transmission lines and national roads. It is anticipated that the total damage cost was approximately USD 9.6 million. In correlation to this, floods in the Eastern Cape Province of South Africa manifested in June 2025 and claimed more than 80 lives and damaged more than 40 households. Then the author concludes that there is a need to improve disaster

management plans which includes disaster centres and develop frameworks for disaster prevention and mitigation. It is however noted that these mitigation strategies proposed by the author cannot be able to mitigate continuing climate changes but will act as a control measure for managing disaster.

In essence, the above and other devastating environmental climate changes need far more mitigation measures beyond control measures of managing the outputs of climate disaster. The United Nation (UN) through Sustainable Development Goal (SDG) 7 has proposed all nations to ensure access to affordable, reliable, sustainable and modern energy for all. According to [9,10], SDG 7 promotes affordable and clean energy while in pursuit of private investments and economic growth. On the other [11] argues that despite so many strategies, policies and frameworks proposed by individual countries to achieve SDG 7, there is still a huge gap to achieve clean, sustainable and affordable energy. The principal argument is that it remains challenging if not impossible to fully transition from fossil fuels to renewables since industrials and society highly depends on these for energy generation which ultimately create significant amounts of carbon and nitrogen dioxide emission and thus global warming. A key finding of this study is that energy transition is possible through effective implementation of energy policies.

III. THE ROLE OF ENEGY POLICY IN THE CONTEXT OF SOUTH AFRICA

Energy policy developments in South Africa can be traced back from 1960s with its focus on electricity and coal policy [12]. In his study [13] assesses the origins and development of South African energy policy and further evaluate a detailed history of four categories of energy policy, including nuclear policy, liquid fuel policy, coal and electricity policy. The methodology used by the author to evaluate the study was consultation of documentation, interviews, and reports. The study concludes that the development of energy policy in South Africa is substantially influenced by the energy system structure and apartheid era. Lastly the author recommends that to resolve issues of energy poverty and global warming effectively, future policy developers need to ensure effective measures of policy road maps and energy structures.

Over the past decades major developments in energy policy have emerged, which attempts to cover much broader scope that include sustainable energy policies and other energy frameworks. In actual policy developments, South African energy policies are expected to meet obligations of Paris Agreement [14]. The Paris agreement proposes that countries reduce global emission by implementing sustainable energy developments to address issues of climate change. Author [14] argues about policy barriers to energy transition in South Africa. He then reveals factors such as fear of the unknown, lack of finance, political instability as the major contributing factors to policy barriers. Despite the above factors, the author further indicates that energy policy is mainly affected by people and politics. He then concludes and refers to lack and absence of energy masterplan and rigorous national policies.

Energy policy is a framework developed to successfully measure, monitor and control the implementation of energy security, environmental protection and promote competitiveness in energy industries. Among other energy policies in South Africa are National Energy Act of 2008, Energy policy White paper, Electricity Act, National Development Plan Vision 2030, Integrated Energy Plan, Electricity Regulation Act 4 0f 2004, and Renewable Energy Independent Power Producers Procurement Program (REIPPPP). South African Renewable Energy Master Plan (SAREM). These and other policy frameworks articulate a roadmap and energy planning for South Africa to tap into opportunities of energy development and economic growth.

South African government, particularly department of energy (DOE) is a body responsible for the development of national energy policies. Policies are then developed for transformation, growth and redistribution of energy within the country and beyond. In determining and developing energy policies, considerations are made to social, economic and environmental policies. In addition, a broader aspect of South African energy sector, policy goals, global and local competition in energy generation are also considered.

The objective of Integrated Energy Plan (IEP) is to develop an energy framework and strategies to address the need for sustainable energy and energy security in South Africa [15]. The article suggests that the development of Integrated Energy Plan resulted from Energy Act no 34 of 2008 and White Paper on

Energy policy. As a result, IEP provides a strategic direction to future energy investments, new technologies, economic expansion through energy security and cost of energy. In contrast, IEP presents roadmap for addressing deteriorating energy resources, geopolitical instability, insufficient energy and natural disasters [16].

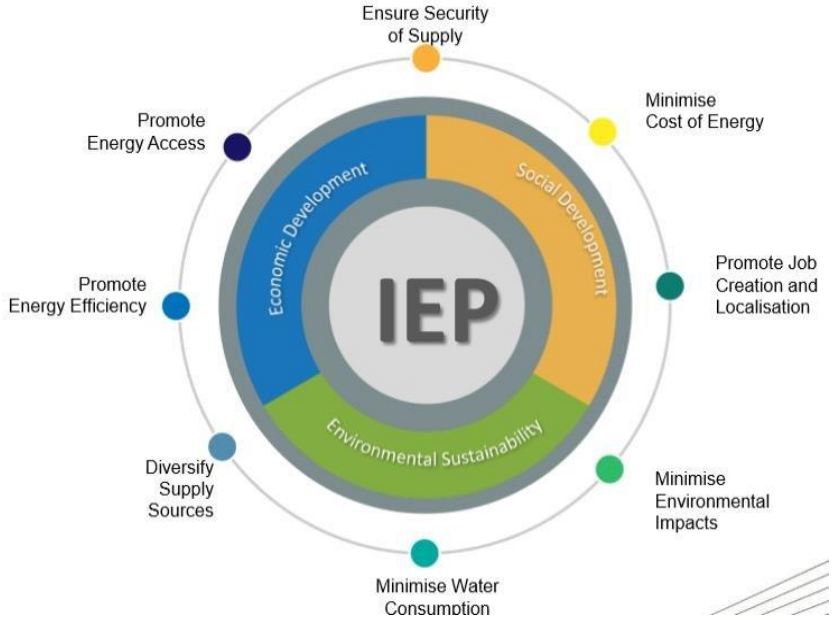

Figure 1: Integrated Energy Plan

Figure 1 presents the overall ideology of Integrated energy plan IEP. The outside layer of figure 1 presents the proposed eight key objectives of IEP as well as three key sectors of consideration in energy developments. The objective of environmental sustainability inclusion in IEP is to pursuit the emission reduction and decarbonisation. The importance of decarbonisation in energy sustainability cannot be underestimated. In his study [17] suggests that to achieve low carbon economy the is a necessity to shift towards green energy generation. This study highlights the importance of grid integration with renewable energy sources (RES) to achieve environmental sustainability and economic growth. There are two principal arguments to consider in this study, Firstly, can all energy policies developed enable effective utilisation to achieve decarbonisation and foster renewable energy integration. Secondly, author argues whether grid integration of renewable energies in generation value chain can be able to accomplish low pollution and clean energy. It is noted eventually that the author does not concentrate much on energy policy developments in the study but rather strategies of low carbon economy. A key finding of this study is that even though South Africa has abundance of renewable energy sources, however transitioning to low carbon economy highly depends on both stakeholders and government.

Several authors have demonstrated that the concept of environmental sustainability and its aspects differs with the sectors applicable to nevertheless its objective remains the same [18,19]. For example, environmental sustainability in energy generation particularly coal fired power plants will be to address the need for reduction of air pollution created using coal and other fossil fuels. Similarly, environmental sustainability in agricultural industries will be ecological balance and to preserve natural resources. In addition, environmental sustainability in transportation industry will be transport mobility by reducing greenhouse gas emission (GHG) and improving air quality. Owing to the above, IEP lacks detailed methodology to employ to assess economic, social and environmental sustainability.

Life cycle assessment (LCA) is a life cycle-based system that can be utilised to assess the environmental impacts of energy generation and compare two alternatives' products or services to provide decision [20]. For example, LCA can be used to potentially examine the extent to which coal is used in power plants contribute to pollution versus the use of renewable energy plants to achieve environmental sustainability. It is important to note that IEP proposes job creation and localisation potential as one of the key objectives. The principal argument in this objective is to create job opportunities through implementation of energy

generation projects through sustainable developments in solar, wind and nuclear. IEP further anticipates achieving and localise 85% of job creation. Despite this idea of job creation, the IEP lacks the strategy of how the job creation will be achieved. In essence, job creation through energy implementation requires a diverse collaboration between government and private sector organisation. Therefore, the approach in job creation particularly localising 85% of job creation depends on various factors such as skills and expertise on engineering and construction. Similarly, energy generation projects require highly skilled engineers, technologies and technicians to effectively implement these projects.

The South African Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) is a strategy implemented by South African government to promote competitive investment into grid renewable energy generation [21]. This procurement programme encourages public to private sector partnership by outsourcing the infrastructural developments of renewable energy projects. Certain stakeholders involved in the participation of the IPP among others include government.

The author [22] suggest that the development of independent power producer (IPP) programme was influenced by Electricity Regulation Act 4 of 2004 and Sustainable Development Goal (SDG) 7 to achieve reliable and effective energy supply. The study examines the constraints and achievements of implementation and management of IPPs in South Africa's energy value chain. The author argues that IPP programme need to resolve the challenges of South African energy sector in power outages, supply and demand of electricity, and challenges in maintenance and infrastructure which negatively impact social and economic growth. Then the author used different methodologies of data collection which include amongst others government reports, journals, legislative reports and conference papers. The analysis and the result of the study shows that REIPPPP has substantial achieve great results. The procurement strategy however has not been presented by the author.

The Integrated Resource Planning (IRP) is South African strategic framework for energy generation. The objective of this framework is to plan and position energy supply to energy demand whilst ensuring energy security, reducing cost of supply and greenhouse (GHG) gas emission. It emerges from government gazette [23] that an IRP framework is a living document that is continually reviewed and improved to meet the desired needs and demands of energy value chain. Therefore, during the review of this framework factors such as plant performance, plant breakdowns, Eskom plant Challenges, and energy availability factor (EAF) are significantly considered. Because of this, IRP therefore promotes the diversification of energy generation through energy mix. Energy mix is defined as a strategy of obtaining energy security through diverse and sustainable energy generation. The importance of energy mix and role of energy independence cannot be underestimated because it encourages utilization of alternative energy sources and minimize dependency from single source energy supply [24]. The study [24] explores numerous frameworks, procedures and systems to enhance energy mix whilst minimise energy independence. The main argument of this study is that this can have significant economic and environmental gains. For example, countries like North America, Europe, China, and India have witnessed stable energy consumption a relatively increasing economic growth. Furthermore, the study highlights the strategies for energy diversification as implementation of emerging energy technologies such as energy storage, grid management, renewable energy integration, economic incentives and energy policies. The study concludes that in pursuit of energy diversification energy policies and strategic energy frameworks plays a significant role.

Since 2007 South Africa has witnessed energy crisis of continuous national widespread power blackouts and power outages. These devastating unplanned outages has severely impacted the economic growth and the wellbeing of citizens [25]. The study [25] estimates the economic cost implications of loadshedding in South Africa. Author collected data through Eskom weekly data on for a period of thirty-three months of loadshedding occurrence. Author argues that business have been severely affected by loadshedding as a result many have shutdown. In addition, the latter has negatively affected investor's confidence to invest in the country. The findings indicate that from year 2007 to year 2019 South African economy has lost USD 1.9 billion in economy and revenues.

As a results of this and other factors, South African government has since implemented several strategies, frameworks and plans to restore generation stability and increase capacity generation. Eventually in 2024

Energy Action Plan (EAP) was developed and implemented as measure to end loadshedding and achieve energy security. EAP appointed National Energy Crisis Committee (NECOM) to facilitate and implement plans to restore electricity. Since the development of EAP there has been a great success and progress in improving generation capacity and energy security. As a result of EAP implementation [26] suggests following milestones were achieved:

- Recovery of Kusile Power Station Unit 3 ahead of schedule.
- New Capacity Development of 7615 MW Window 7 ESIPPPP 2 battery storage and Gas IPPP.
- Short- term energy procurement from Utilities outside South Africa.
- Development of Electricity Regulation Amendment Bill.
- Western Cape Worcester Battery energy storage with total capacity of 833 MWh.
- Northern Cape Kunhardt Risk mitigation project with additional 150MW.
- 3.4 GW additional capacity for Windows 7 project support.
- Businesses and Household Rooftop Solar panel resulted to 5000MW.
- Introduction of the 12B tax incentives and financial support for renewables.

In pursuit of green energy, South African government has introduced renewable energy tax incentives under section 12B of the Income Tax Act. The role of tax incentive and other financial support is to encourage the private sector renewable energy generation to reduce loadshedding and impact of emission [27]. In addition, section 12B of Income Tax incentive as effective from 1 March 2023 to 28 February 2025 for the period of 2 years, allows business who installed asset of electricity renewable generation such as wind, hydro and solar energy to offset the first year up to 125% of the total cost invested to assets of energy generation payable to South African Revenue Services (SARS). Therefore, it is important to note that this will significantly reduce tax for renewable energy investments.

Furthermore, EAP has provided Free Basic Energy (FBE) which is the financial support provided by Eskom and Municipalities to local or households through equitable share. Through this fund from National Department allocates equitable share to poor households who cannot afford basic electricity. The amount of 50 kWh is allocated to households identified by supply authorities to need compensation.

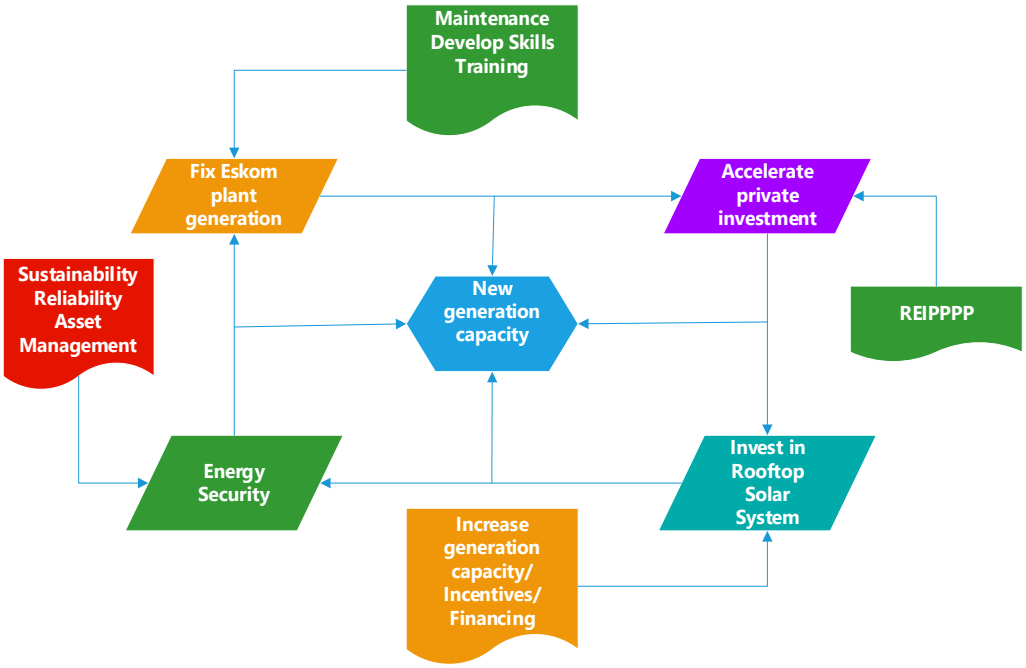

Figure 2: Energy Action Plan Flow Chart

Similarly, the acceleration of private sector investment energy generation has received an overwhelming support in all sectors of government. Through REIPPPP there has been huge private sector investments in renewable energies. Over 120 renewable energy projects have been implemented throughout the country. Also, the licensing requirement was removed from embedded generation. Another key development was the development of Eskom battery energy storage system (BESS).

Figure 2 present the overall methodology of Energy Action Plan (EAP) in pursuit to end loadshedding, increase energy capacity and energy security. There are further four key areas of focus demonstrated within EAP framework which include energy private sector participation, investing in rooftop solar system, fixing Eskom plant generation and management of asset. The critical points to consider was the development of generation recovery plan to increase plant performance and reliability. As a result, a reduction of plant breakdowns and improve planned maintenance programmes emerge to produce more than 8000 MW. Furthermore, distribution demand management programme was developed to reduce demand on the grid.

IV. ANALYSES OF THE STATE OF ENERGY DEVELOPMENT IN SOUTH AFRICA

Primarily over the past fifty decades, coal supply has been the majority energy contributor in South Africa energy generation. In contrast, South Africa comprises of 19 coal fired power generating plants situated mostly in the Mpumalanga province of South Africa while others are in Limpopo Province.

TABLE 1: COAL FIRED POWER PLANTS

Power Station	Total Capacity	Location	Year Built
Arnot	2352 MW	Mpumalanga	1971-1975
Duvha	3600 MW	Mpumalanga	1980-1984
Hendrina	2000 MW	Mpumalanga	1970-1976
Kendal	4116 MW	Mpumalanga	1988-1992
Kriel	3000 MW	Mpumalanga	1976-1979
Lethabo	3708 MW	Free State	1985-1990
Majuba	4110 MW	Mpumalanga	1996-2001
Matimba	3990 MW	Limpopo	1987-1991
Matla	3600 MW	Mpumalanga	1979-1983
Tutuka	3654 MW	Mpumalanga	1985-1990
Camden	1510 MW	Mpumalanga	1967-1969
Grootveil	1200 MW	Mpumalanga	1969-1971
Komati	940 MW	Mpumalanga	1961-1966
Medupi	4788 MW	Limpopo	2015-2019
Kusile	4800 MW	Mpumalanga	2017-2025

From the above Table 1, the list of South African coal fired power plants is shown. The coal generation has been the mostly widely used power generation in South Africa since early Sixties, with most of its power plants situated in Mpumalanga province of South Africa. South Africa is largely dominated by coal generated energy supplies. In essence, majority of South Africa's coal fired power plants have reached their life expectancy of 25 years in operation. Due the amount of flue gases created by these power plant, power utility has been confronted with critics to reduce its gas emissions to acceptable levels.

TABLE 2: RENEWABLE ENERGY POWER PLANTS

Power Plant	Total Capacity	Location	Year Built
Drankesburg pumped storage scheme	1000MW	Free State	1981
Ingula Pumped Storage Scheme	1332 MW	Kwa-Zulu-Natal	2017
Gariep Dam	360 MW	Free-State	1971
Palmiet Pumped Storage Scheme	400 MW	Western Cape	1988
Colley Wobbles Power Station	42 MW	Eastern Cape	1984
Sere Wind Farm	100 MW	Western Cape	2015
Amakhala Emoyeni	131.05 MW	Eastern Cape	2017
Aurora Wind Power	90.82 MW	Western Cape	2013
Thaba Wind Farm	21 MW	Eastern Cape	2015

The above Table 2 shows among others some of renewable energy power generating plants across South Africa. These renewable energy power plants comprise of hydropower plants, wind farms and solar power plants which are interconnected to the national grid. These plants are playing a crucial role in environmental sustainability, and energy security. Recent energy projects include renewables and energy storages plants.

It can be noted between Table 1 and Table 2 the difference of energy generated by coal power plants compared to renewable energy plants. Energy generated by coal power plants is very much higher compared to energy generated by renewables. In contrast, energy generated by using fossil fuels is the core of energy generation in South Africa. Therefore, environmental pollution is mostly created by fossil power plant. Even though Eskom reaffirms its commitment for minimising environmental pollution by 40% in 2030, there are many challenges involving installation of fabric filters and desulphurisation technology. For example, for the installation of technologies such as fabric filters, electrostatic participators and ultra-low NOx burners need complete plant shutdown to retrofit.

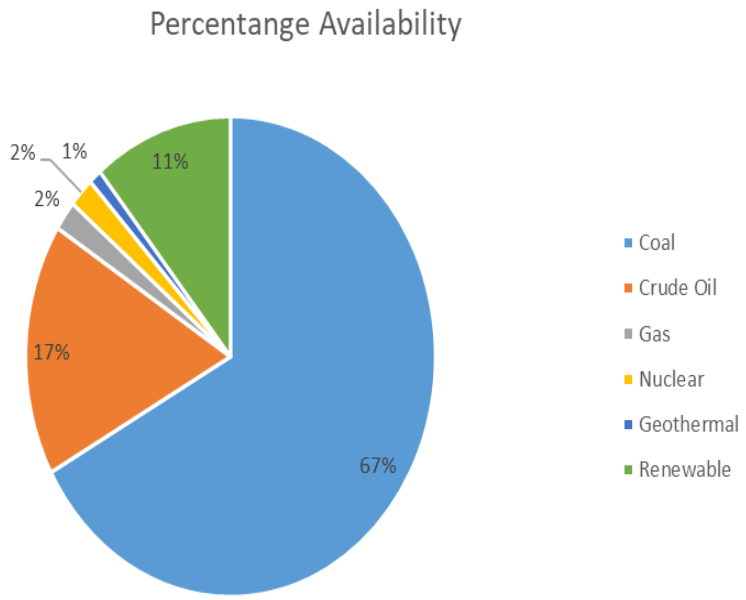

Figure 3: Energy Supply in South Africa

In Figure 3, the Department of Mineral Resources and Energy (DMRE) in 2022, Has reported that highest used energy supply is South Africa is coal with 67% supply, followed by crude oil at 17%, then renewable energies are at 11%, gas and nuclear are supplying 2% each and the least is geothermal which supply 1% of energy [28].
Renewable energy sources among others include solar energy, wind energy, bioenergy, geothermal, hydropower and ocean energy [29]. The role of Renewable Energy Independent Power Producer Program (REIPPP) is to produce additional energy to the grid to ensure reliability and stability of power supply. The South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is a competitive tender process that was officially launched in August 2011 to procure 3,7 GW of renewable energy capacity in private sector investment into grid-connected renewable energy (RE) generation [30].
Similarly, the efforts of decarbonization have resulted in increased grid integration by renewables. Battery Energy Storage Independent Power Producers Procurement Programme (BESIPPP) projects BW1 to BW8 have also played a crucial role in stabilizing the grid. It is estimated that by 2030 approximately 22.9GW will be procured though renewables. It is also estimated that approximately 13GW has been injected to the grid by both solar and wind energy grid integration.

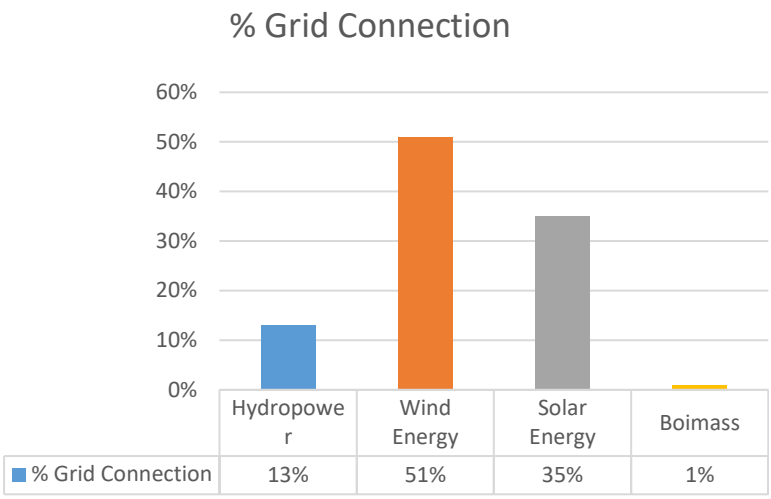

Figure 4: Renewable Energy Grid Connection

In Figure 4, the percentage of renewable energy grid connection is shown. The above Figure 2 shows the statistics derived from independent power producers and it is noted that onshore wind energy is contributing 51%, followed by solar energy generating 35%, hydropower producing 13%, and biomass energy at 1%. In 2019, the total energy generated by the IPPs in South Africa amounted to 11 836 GWh. It is noted that from the above statistics that the grid interconnection of small, embedded generation is excluded. Renewable energy generated by domestic, commercial and industrial institutions also plays a significant role in reducing energy demand through off grid interconnection. Off grid renewable energy interconnection completely isolates from using utility power supply and only dependents on renewable energy.

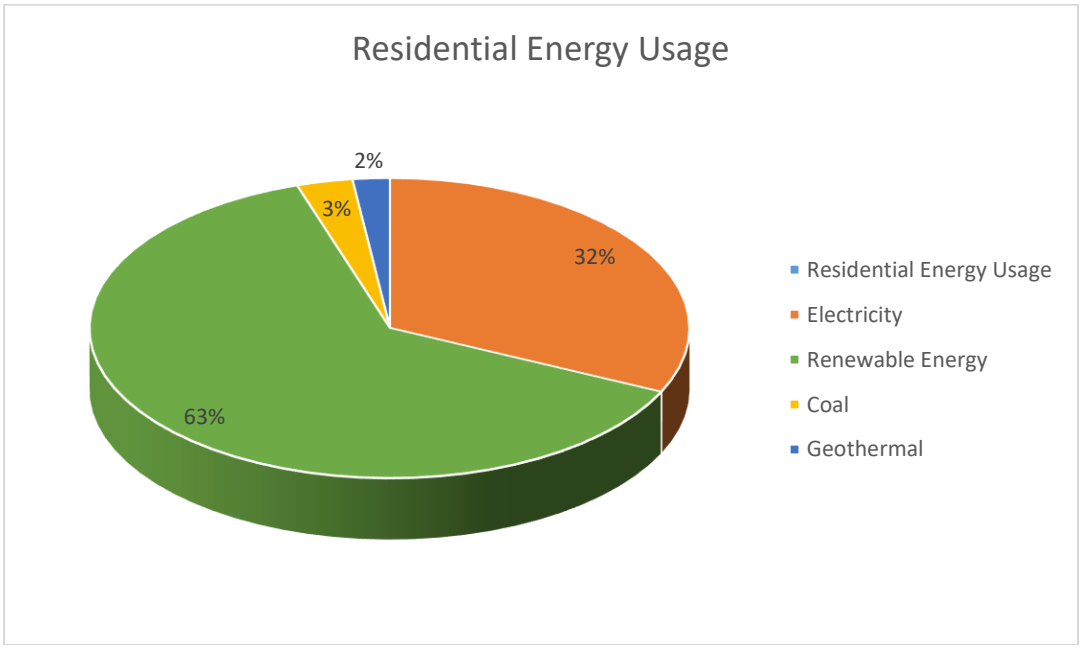

Figure 5: Residential Energy Usage

The above Figure 5 shows the energy usage by residential areas in South Africa. It is noted that renewable energy is the mostly used for residential use with 63%, while electricity generated by utility is 32%, energy generated by coal is 3% used and geothermal is the least energy used in residential areas with 2%. The power utility has been struggling to keep South Africa's lights on and is one of the reason why there is a high rate of renewable energy exploration usage in residential arears. The renewable energy in residential areas is essential because it provides a basic access to electricity through low cost and maintenance supply of energy.

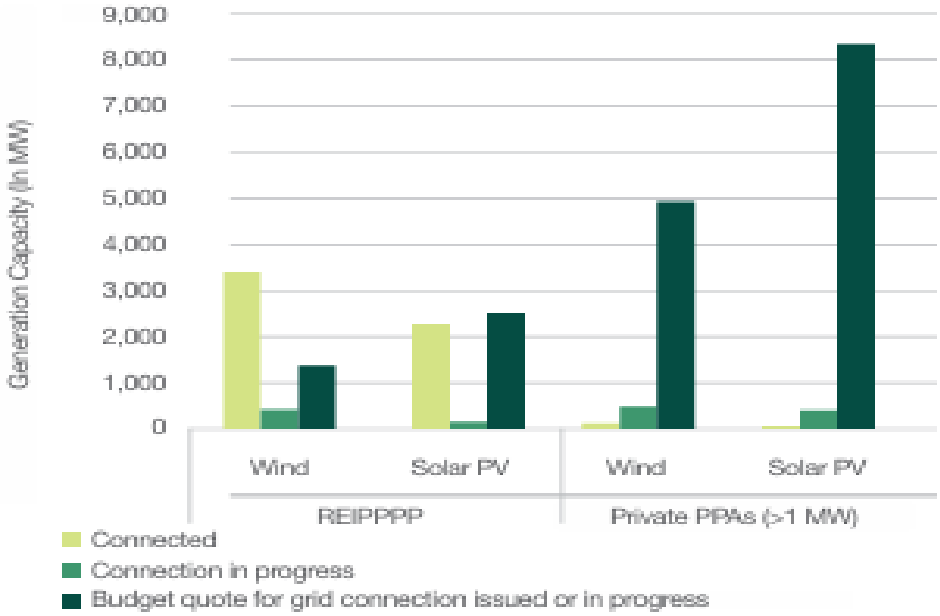

Figure 6: Renewable energy generation capacity >1 MW [31]

Figure 6 shows renewable energy generation greater than 1MW already connected to the load and other in connection progress. Figure 6 further supports and concurs with statistics provided in figure 5 by particularly presenting 800MW and approximately 343MW for both solar and wind power already connected to the load from 2011 to 2022. Furthermore, an anticipated 5000MW under BW7 and 5000MW in BW8 is estimated to be procured [31]. It is important to further note rapid increase in municipality small-scale embedded generation (SSEG). This has resulted in increased households, businesses and industrials investing in solar power. Policy framework has made provisions for incentives to encourage the use of renewables.

TABLE 3: STATE OF HOUSEHOLD'S ELECTRIFICATION

Province	Projected Household	Total Houses Connected	Total Houses not connected	Houses Electrified	Access per Province
Eastern Cape	1 863 009	66 243	323 411	1 539 598	82.64%
Free State	909 007	4 586	123 589	785 418	86.40%
Gauteng	4 315 876	11 876	776 997	3 538 879	82.00%
Kwa Zulu Natal	2 803 735	70 765	485 472	2 318 263	82.68%
Mpumalanga	1 187 426	33 496	88 320	1 099 106	92.56%
Northern Cape	332 775	3 400	44 196	288 579	86.72%
Limpopo	1 565 699	58 666	22 723	1 542 976	98.55%
North West	1 172 550	16 271	158 795	1 013 755	86.46%
Western Cape	1 804 068	10 527	185 394	1 618 674	89.72%
Total	**15 954 146**	**275 830**	**2208 898**	**13 745 248**	**86.15%**

Table 3 indicates the state of electrification in South Africa. Limpopo province is noted to be the leading province in electrification with 98.55% and Eastern Cape is the lowest province in electrification with 82,64%. Despite a significant growth in electrification of households in South Africa over the past 20 years, [32] suggest that factors such as illegal land occupation by informal settlers in urban areas hinders process of electrification. Furthermore, theft of electrical cables also contributes household electrification. The high rate of cost of electricity in South Africa has also forced residents to opt for renewable energy. Despite continuous increasing electricity costs and non-reliability of Eskom power supply it is shown in Figure 3 that several organizations both private and government are still highly dependent on utility's

power supply. These institutions however have suffered from profit loss, decreased investments, loss of employment and loss of production [33].

V. CONCLUSION AND RECOMMENDATION

Renewable energy investments in South Africa have risen beyond expectations and have unlocked many opportunities including job creation, economic growth and sustainability. It is no doubt that the continuous rollout of renewables and energy storage has benefited the communities and increased energy access. Programs like REIPPPP have received a great attention and have been created more than 20 000 local jobs. Furthermore, through project Bid Windows 1 to 4 more USD 11.2 billion in local economy has been invested. These policies also offer great opportunities for competitiveness through public and private sector participation.

Energy policies, strategies and frameworks in South Africa have shown a great influence, impact and shift towards energy access and energy security. The influence of energy policies, particularly renewable energy programs and framework have been fruitful in implementing new energy projects and new energy generation capacity. The strategic vision of the government in the rollout of renewable and energy storage has yielded great results. As a result of these policies electricity generation networks and grid reliability and stability have improved.

South Africa has witnessed an increase in residential and industrial renewable energy access. It is estimated that more than 63% residential and industrial have access to renewables and more than 86.15% have people have access to electricity. This is made possible by government programs like National Development Plan (NDP) Vision 2030 and other strategic plans. In addition, Integrated Energy Plan (IEP) and Energy Act have also played a crucial role in developing strategies to improve Eskom power plant's reliability. It is through strategies like Energy Action Plan (EAP) that South Africa has reduction in loadshedding.

The continued efforts of government through NDP in expanding energy capacity of industrial factories via energy renewables and energy storage has boosted the Gross Domestic Product (GDP) and economic growth. This has eased the continued rising energy demand and supply. Furthermore, it has contributed to local job creation and skills development. Programs like Energy Action Plan has been solely implemented to focus on improving Eskom plant breakdowns and reducing loadshedding. This program further appointed a committee to control and monitor the progress of this action.

Despite intervention of these policies, it is noted from the study that the use of fossil fuels continues to contribute to air pollution. This is due to energy generation through coal fired power plants. This has resulted in climate change and environmental pollution. It is evident through recent flood in KwaZulu Natal in April 2023 and in Eastern Cape in Mtata in June 2025. The study recommends that special attention should be paid to set measures to reduce carbon dioxide emissions from power plants.

Lastly, policy and strategy implementation on the other hand also are not persuaded without any challenges. There has been challenges in implementation of REIPPPP framework in between 2015 to 2019 because of local rules. Grid integration constraints and policy framework amendment further create various delays in renewable energy roll-out. The study therefore recommends public participation in policy framework developments. Public participation includes consultation with private sector investments. This will help reduce the challenges of policy uncertainty and improve market developments.

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