EMP-A

Modelling the decarbonization pathways of Rwanda's power system and ensuring energy security

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5th May 2025

Keywords: Energy system modelling, imports, renewable energy, OSeMOSYS.

Acknowledgements

- This report was created as a result of an engagement with EMP-A which was organised by Climate Compatible Growth, United Nations Economic Commission for Africa, World Bank Group, and Sustainable Energy for All.
- The OSeMOYSYS trainers involved in guiding the development of the report were from RE-INTEGRATE and CCG.
- The authors of this report were funded by Darnish Energy Agency.
- This material has been produced with support from the Climate Compatible Growth (CCG) programme. CCG is funded by UK aid from the UK government. However, the views expressed herein do not necessarily reflect the UK government's official policies.

Executive Summary:

This report was developed during the Energy Modelling Platform for Africa 2025 in Addis Ababa, Ethiopia. The input data was received from different sources for the past 3 years (2021-2023). The data included primary sources of energy and its reserves, power installed capacity, generated electricity and demand.

Through the MUIO – Osemosys, three scenarios were studied and these were:

- BAU – considering the committed plants and plans of the Rwanda;
- Import reduction-reduction of power imports that affect the grid stability and
- Renewable energy target- constraining the Renewable energy share at 70% from 2030- 2050 in line with the SDG and NDC targets.

Key Findings:

Under the Business-as-Usual (BAU) scenario—where no additional policy interventions are introduced—the model identifies power imports as the dominant supply source by the end of the planning horizon. This outcome reflects the model's least-cost optimization framework, which favors imports due to their relatively lower cost. For policymakers, this underscores the importance of ensuring cross-border infrastructure readiness, particularly the expansion and reinforcement of transmission networks. However, such heavy reliance on imports raises strategic concerns around energy security and grid stability, emphasizing the need for grid strengthening investments to manage operational risks and ensure reliability.

In the first policy scenario, designed to enhance energy self-sufficiency, the model imposes constraints on power imports to prioritize domestic generation. This encourages the deployment of technologies such as solar PV and already committed plants. From a planning perspective, this approach supports local capacity development and reduces external dependence. However, it also results in higher annual emissions compared to the BAU case due to the increased use of fossil-fuel-based technologies, notably natural gas and coal. This presents a trade-off that policymakers must weigh between energy security and environmental sustainability.

The second scenario aligns with the country's ambition to meet its Nationally Determined Contribution (NDC) targets. Here, the share of renewable energy is capped at 70% between 2030 and 2050 to balance reliability with emissions reductions. The model outcome shows that imports re-emerge as a cost-effective complement, which reinforces the critical role of regional interconnections and the need for grid investment to absorb variable renewable energy and ensure system stability. Solar power continues to dominate the renewable mix, highlighting its central role in Rwanda's clean energy transition.

Recommendations:

- Invest in Transmission lines for power importation and Grid Strengthening projects for stability and reliability purposes.

- Engage in the Power trade agreements with regional power pools to ease the importation of power.
- Achieving the renewable share target is possible but it requires huge investment in RE technologies and batteries to deal with their intermittency.

I. Introduction:

Rwanda's energy system relies on a mix of hydropower, solar energy, imported electricity, biomass, and fossil fuels such as diesel, coal and natural gas. The total grid installed capacity is 406.4 MW (REG, 2025). Hydropower remains the dominant source of electricity generation, but solar energy has grown rapidly in recent years. The country is increasingly focusing on renewable energy sources while aiming to reduce dependence on fossil fuels. Rwanda's government has committed to achieving a 70% renewable energy share in electricity generation by 2030, as part of its broader sustainable development goals and climate action strategy. In addition to hydropower and solar, Rwanda is also exploring biomass, geothermal and wind as potential contributors to its future energy mix.

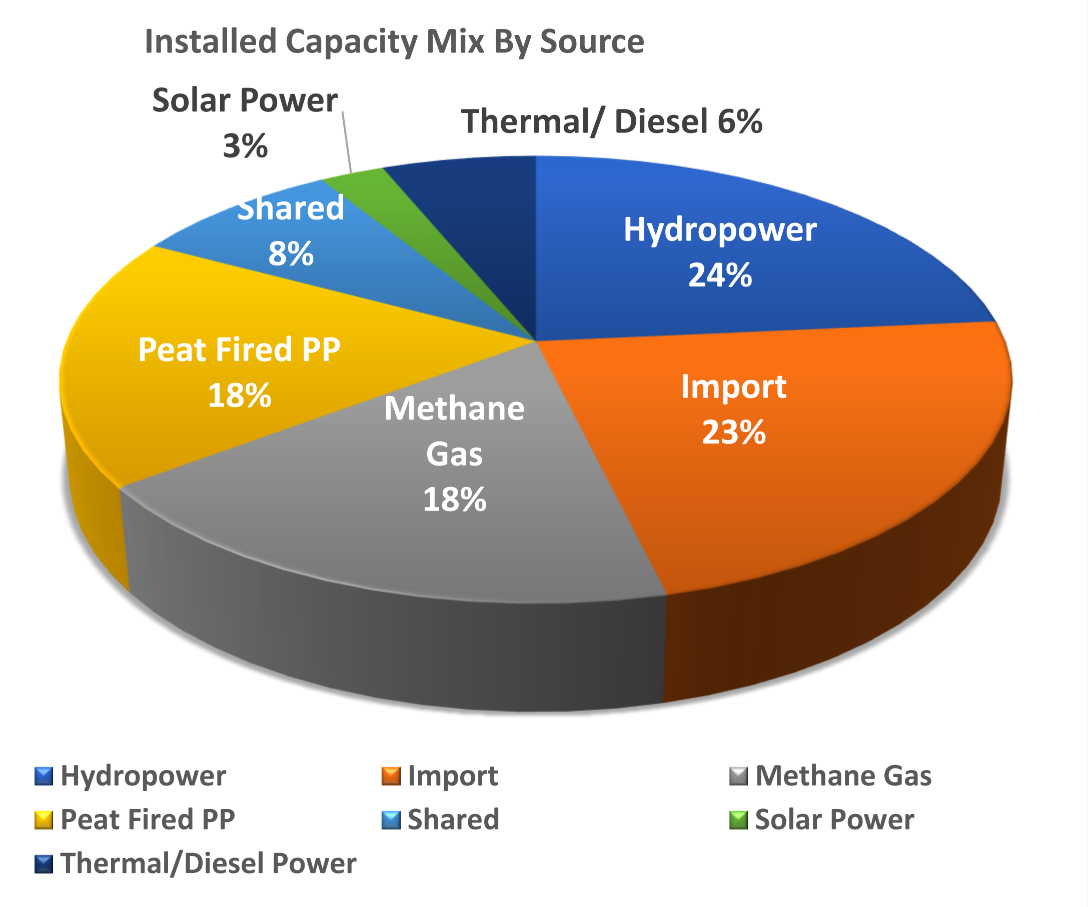


Figure 1: Installed Capacity mix

However, the energy system faces several challenges, particularly during the dry season as reduced water availability leads to a decline in hydropower generation. Furthermore, reliance on electricity imports reduces the reliability of the power system. To overcome some of these challenges, Rwanda often resorts to costly, diesel-based rental generation to meet peak demand.

These issues highlight the importance of diversification and resilience in the domestic generation plans, especially considering the country's commitments under its Nationally Determined Contribution (NDC), which aims to reduce greenhouse gas (GHG) emissions by 38% by 2030 and achieve carbon neutrality by 2050 (REMA, 2020).

This study aims to assess the implications of electricity imports during the modeling period, with a particular focus on their associated tariffs (costs) in relation to meeting electricity demand. It also explores potential decarbonization pathways for the power sector, specifically examining the feasibility of achieving national renewable energy targets. The scope of the report is limited to the power sector and does not extend to an analysis of the broader energy sector.

Aim:

To model a least cost generation mix to meet electricity demand while ensuring a 70% share of Renewable Energy.

Objectives:

1. Satisfy the demand with a least cost plan
2. Ensure the utilization of natural resources with domestic generation.
3. Ensure 70% of the generated power is from Renewable sources.

II. **Methodology**:

This study adopts a mixed-method approach to assess the impact of demand growth, imported energy on the performance of Rwanda's decarbonized power system pathway, with a focus on how the evolution of a green energy mix can support decarbonization targets by 2050 while meeting growing energy demand. The Reference energy system is used as the baseline for modelling the power system, an update of the installed capacities and historical power generation for the years 2021-2023 was implemented to calibrate the model. The methodology of power system modelling, with consideration of imported energy.

Three scenarios evaluated were:
1.The Business-As-Usual scenario (BAU),
2. The Imports Reduction scenario and
3.The Renewable Energy Share scenario

Activities conducted were:

- Reference energy system and Data gathering
- Modelling and scenario analysis (OSeMOSYS)
- Result analysis and policy insights

Data sources:

The utilized data for modelling was researched from AFREC (AFREC, 2021) in identifying Rwanda's energy balance for natural resources and their reserves. The data for resources was also collected from the Rwanda - Electricity Resource Assessment report (EAEP, 2022)

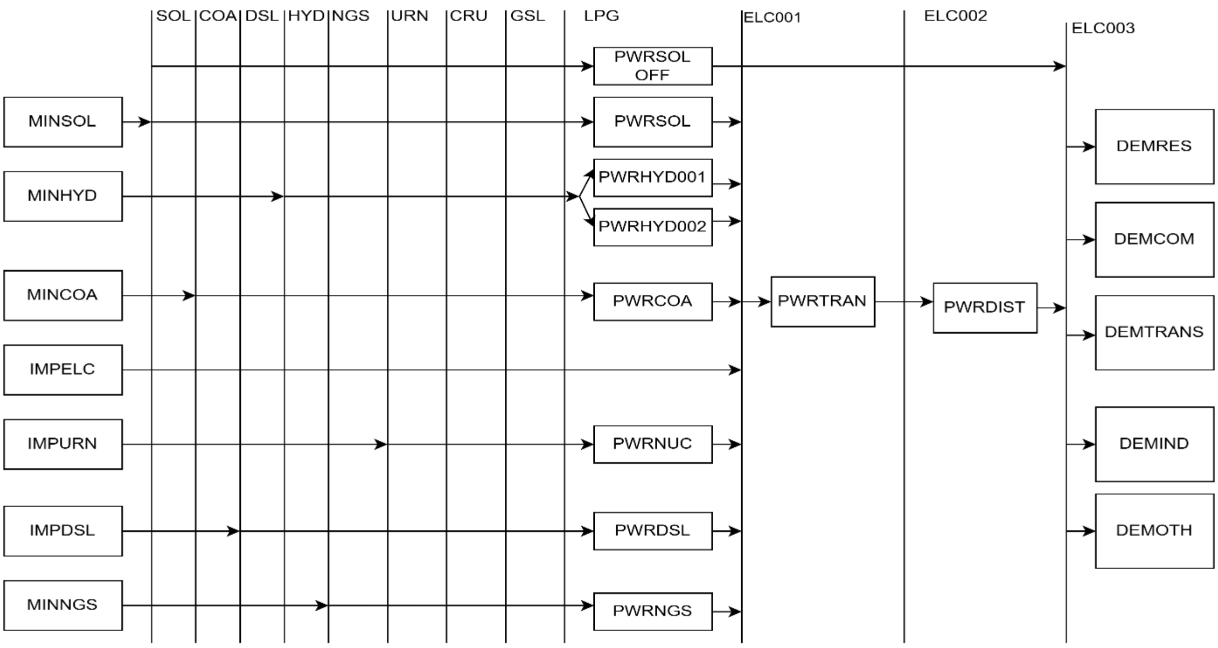
Another alternative to inform the primary energy sources and the demand consumption for other energy sectors other than electricity, was the Energy Balance data developed by a team of Rwanda's Energy Planners during a MESSAGE training session in 2022 in Arusha, Tanzania.

The electricity generated and the share of each demand category was provided from the Rwanda Energy Group's Annual report for the years 2021 – 2023 (REG, 2025).

Reference energy system:

Rwanda's Reference energy system was created to be the baseline for energy modelling data and have a clear picture of the energy sector before narrowing it down to the power sector.

Rwanda's Reference Energy System:



Power System Modelling, Modelling and scenario analysis (OSeMOSYS)

The analysis was conducted using the Modelling User Interface for OSeMOSYS (MUIO), an interface for the long-term energy planning tool Open-Source Energy Modelling System (OSeMOSYS). The optimization of different scenarios of Rwanda's power system carried out using the OSeMOSYS energy modeling framework provided different results and policy insights.
This study aligns with Rwanda's NDCs, including a 38% reduction in greenhouse gas (GHG) emissions by 2030 and the achievement of carbon neutrality by 2050. The results will provide insights into how Rwanda can optimize its energy mix and enhance the resilience of its power system in the face of climate change.

Description of Scenarios

1. **The Business-As-Usual scenario (BAU)**

The Business-As-Usual (BAU) scenario represents the projected development of the energy sector without any additional interventions or policy changes beyond those already in place. It assumes that current trends in electricity generation, demand growth, technology adoption, and energy imports will continue as they are. In this scenario, the energy mix continues to rely heavily on existing sources, such as hydropower, fossil fuels, and imported electricity, and introduces new planned generation such as Nuclear, Geothermal and Wind. BAU serves as a baseline for comparing the impacts of other scenarios.

2. The Imports Reduction scenario

This scenario assesses the impact of reducing electricity imports in order to increase domestic generation and ensure energy security. In this scenario, the total annual maximum capacity was capped from 2030 up to 2050, allowing the model to generate other cost optimum technologies for the period.

3. The Renewable Energy Share scenario

Nationally Determined Contribution (NDC) scenario reflected Rwanda's commitment to reducing greenhouse gas (GHG) emissions and transitioning to a more sustainable, low-carbon energy system, in line with its international climate obligations under the Paris Agreement. This scenario was developed in alignment with Rwanda's NDC targets, aiming to reduce GHG emissions by modelling 70% RES from 2030-2050.

III. **Results**:

The results provided from the model are analyzed using 4 aspects and these include:

- Production by Technology by Mode
- Accumulated New Capacity
- Annualized Investment Cost
- Annual Technology Emission

Below are the Charts and Graphs to showing the results from the model:

a. Production by Technology by Mode

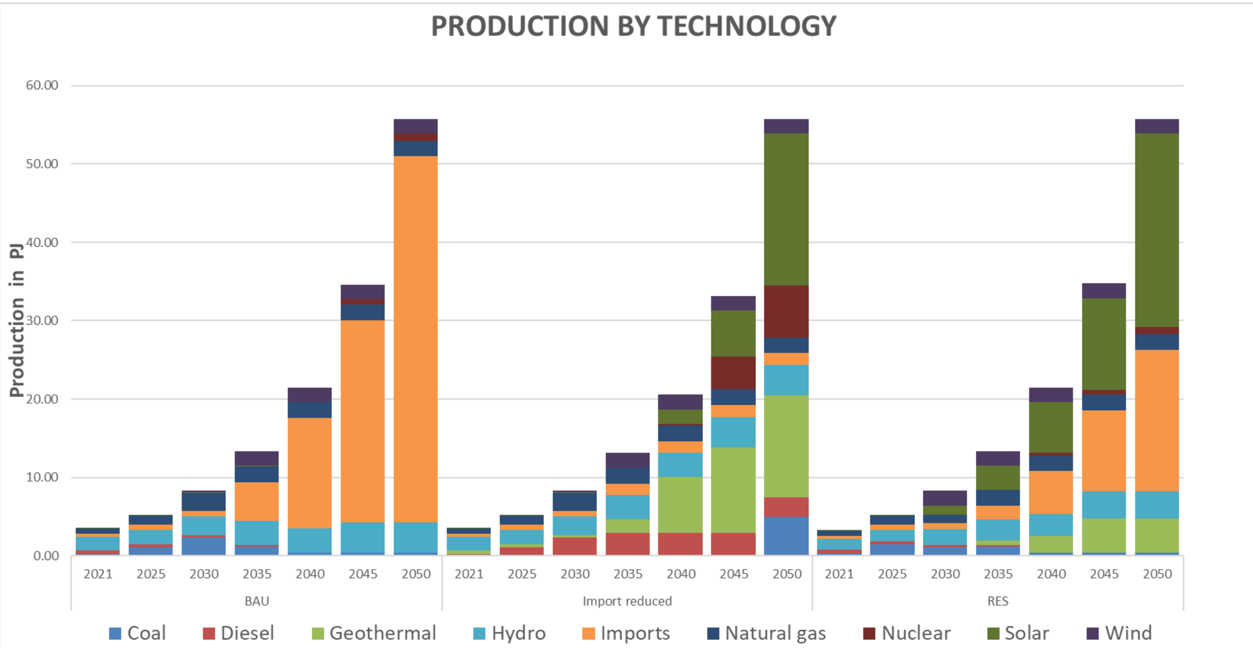


Figure 2: Production by Technology by Mode for all scenarios

Discussion:

1. After capping imports at 150 MW from 2030 onwards, the model prioritizes coal and diesel in the second scenario.

2. The introduction of 70% renewable energy (RE) allows for the reinstatement of imports along with other renewable sources.

b. Accumulated New Capacity

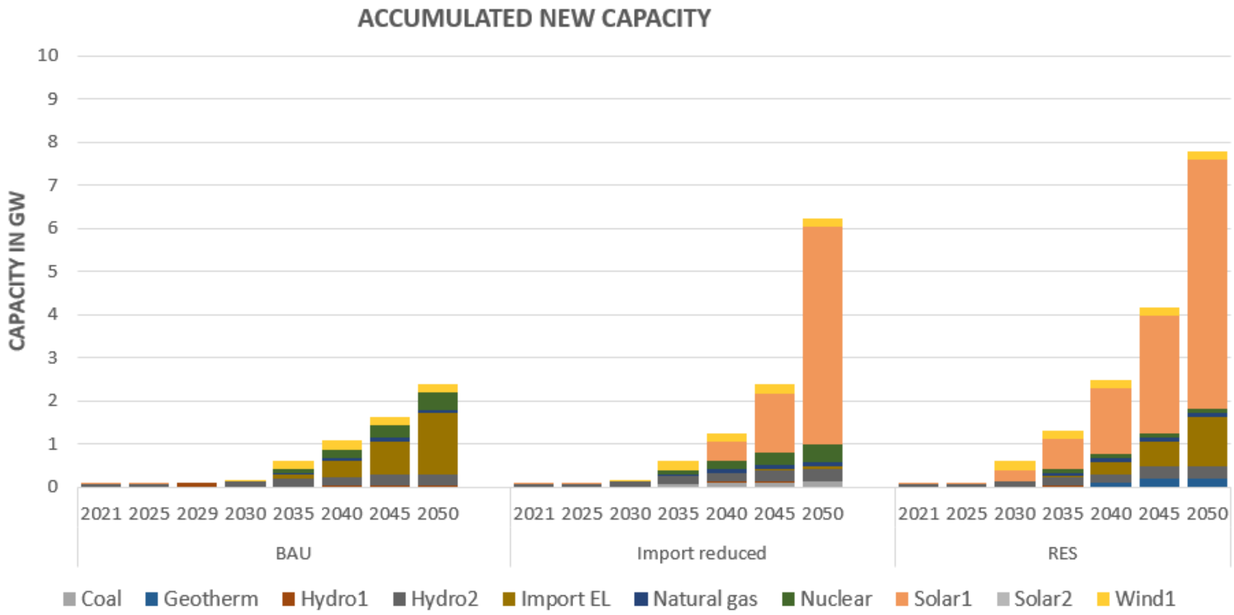


Figure 3: Accumulated New Capacity for All Scenarios

Discussion:

1. Imports are predominant in the Business As Usual (BAU) scenario.
2. Scenario 1 introduces solar, coal, natural gas, and nuclear energy to replace the reduced imports.
3. In contrast, Scenario 2 incorporates solar, wind, geothermal, and imports to meet demand with renewable sources.

c. Annualized Investment Cost

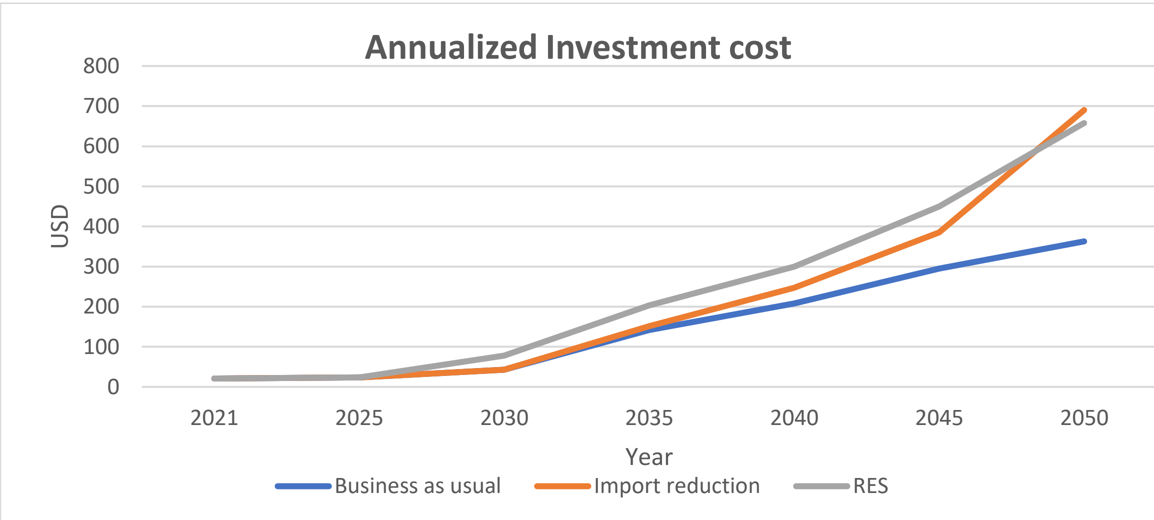


Figure 4: Annualized Investment Cost

Discussion:

1. Both renewable energy sources (RES) and import reductions scenarios require substantial investments; however, towards the end of the modeling period, investment in renewable energy declines.

2. In the years 2047–2048, investments for the import reduction scenario remain high compared to the RES scenarios, which are experiencing a slowdown.

d. Annual Technology Emission

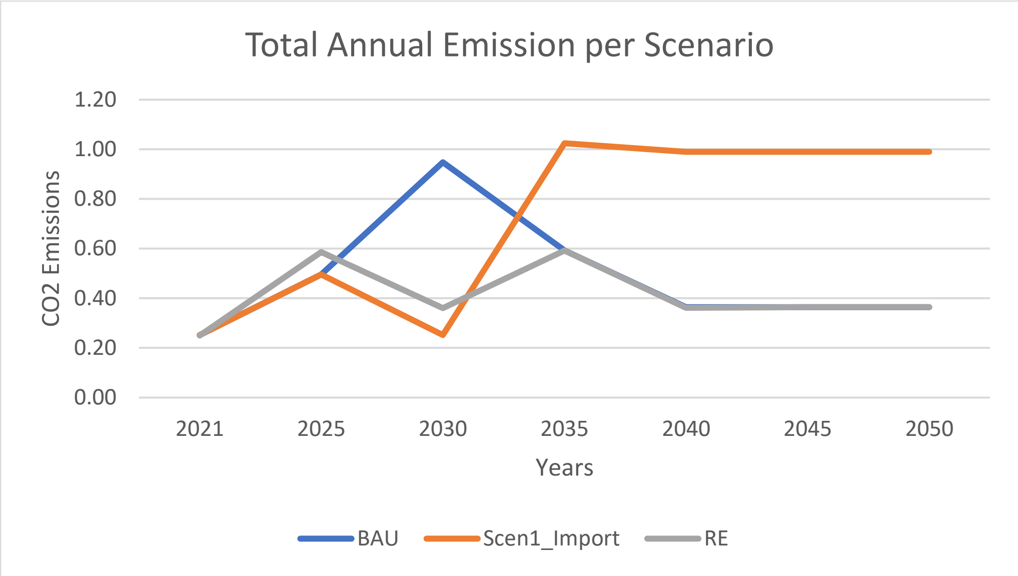


Figure 5: Total Annual Emission for all scenarios

Discussion: The Business As Usual (BAU) scenario emits less CO2 compared to Scenario 1 due to lower emissions from imports. The Renewable Energy Sources (RES) scenario emits the same level of CO2 as BAU from 2040 to 2050.

Main findings of results:

For the BAU scenario, imports dominate due to the cost aspect and it can be verified in the Annual Investment cost with the least cost of below 400 Mn USD.

Imposing reduction of imports affects emission production by increasing thermal/diesel generation.

Renewable Energy Share scenario has shown that imports are necessary to address the remaining 30% of power to be generated from Non- Renewable Energy sources.

Differences between scenarios:

1. It can be easily observed that the renewable energy share scenario has the lowest annual technology emission, followed by BAU and imports reduction scenarios.
2. The annual investment cost is the lowest in BAU because of the cost of imports, followed by Renewable Energy share scenario and lastly imports reduction.

Areas of future research:

Considering that the main issue to assess the impact of power imports was grid stability and reliability. The Government of Rwanda and Rwanda Energy Group are recommended to invest in research about grid protection technologies and grid strengthening projects.

IV. Conclusion:

After assessing the 3 scenarios and analysing the results shown above on production, investment and emission; it can be concluded that even though imports reduction is necessary for energy security purposes; the Model shows that it will increase emission and that will be against the SDG and NDC targets.

Therefore, it is recommended to invest in technologies such as Nuclear, Solar, Hydro, Geothermal and Wind without overlooking the imports to address the demand growth and at the same time reduce emissions.

Further exploration on Renewable energy technologies with potential must be fast-tracked in order to contribute to the target percentage of 70%. These are Geothermal and Wind.

Investment in research and development for improving the performance of existing renewable technologies such as solar is crucial in terms of cost reduction and storage to serve the peak demand.

V. References:

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