Take Home Exam: Assessing the Feasibility of Indonesia's Hydropower Expansion

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Contents

1 Introduction

Indonesia is a country that, historically and today, is heavily reliant on coal and fossil fuels for its electricity generation. The government is determined to phase out coal and fossil-based electricity sources. By 2050 a goal is set to have net zero emissions [1]. A part of achieving this goal is to install new renewable electricity sources. President Prabowo Subianto has pledged to install 75 GW of renewable energy in the next 15 years [2]. The 75 GW of renewables are divided between hydro, pv, wind, geothermal and biomass. The split is 25 GW hydro, 27 GW solar, 15 GW wind, 7 GW geothermal and 1 GW biomass [1]. Indonesia plans to make use of its excellent potential for hydro and pv, which it can attribute to its mountainous topology and sunny days. Even though Indonesia plans to install almost equal capacity of pv and hydro, the way those capacities are used can be completely different. Hydro power is completely controllable, whereas pv is uncontrollable without the availability of buffer systems. Since pv is dependent on weather and time of day, the resulting electricity generated can vary. Hydro can step in and generate more or less electricity depending on how much electricity pv produces. Hydro is as such a base in many zero emission energy systems, such as Sweden and Canada [3], [4]. Since hydro is such a fundamental part of a net zero emission energy system, it is, in this report, considered intrinsic to Indonesia's success of reaching its 2050 goals. Therefore, this report will examine the feasibility of Indonesia's hydro target.

2 Target Description

As of today, Indonesia has an installed capacity of 6.8 GW hydropower [5]. An additional installation of 25 GW in the next 15 years results in an installed capacity multiples higher than the installed capacity as of today. This suggests that hydropower is in the acceleration phase in Indonesia. This can be validated by performing logistical curve fitting on historical capacity data on hydropower in Indonesia. The data is provided by IRENA [6]. A Python script is also available on canvas for logistical curve fitting [7]. After running the script on the data Indonesia is found to have a maturity of ≈ 0 %, which confirms that hydropower in Indonesia is indeed in the acceleration phase.

Since hydropower is in the acceleration phase in Indonesia an appropriate growth metric to define the target by is compound annual growth rate (CAGR) [7]. The CAGR is calculated as:

$$\text{CAGR} = \left(\frac{\text{End Value}}{\text{Start Value}}\right)^{\dfrac{1}{\text{Number of Years}}} - 1 \tag{1}$$

In equation (1) Number of Years is the time span over which to calculate the CAGR. End Value is the installed capacity at the end of the time span, and Start Value is the installed capacity at the beginning of the time span. Inserting the values for Indonesia's planned expansion of hydropower, the targeted CAGR can be calculated.

$$\text{CAGR}_{\text{Target}} = \left(\frac{6.8 + 25}{6.8}\right)^{\dfrac{1}{15}} - 1 = 8.86\%$$

3 Reference Cases

Two reference cases are used for feasibility assessment. One case of high-quality reference countries with a lower amount of data available, and one case of lower-quality reference countries with large amounts of data available. This ensures that the feasibility assessment can be done with respect to both quality and quantity.

3.1 South Asian Countries

Indonesia is not alone in developing renewable energy sources; several South Asian countries are in the process of expanding their renewables and moving away from fossil-based power. Many of these countries share similarities with Indonesia, which makes them relevant references. The South Asian countries examined are: Thailand, Laos, Myanmar, Malaysia, Vietnam, Nepal, and India (see Figure 1).

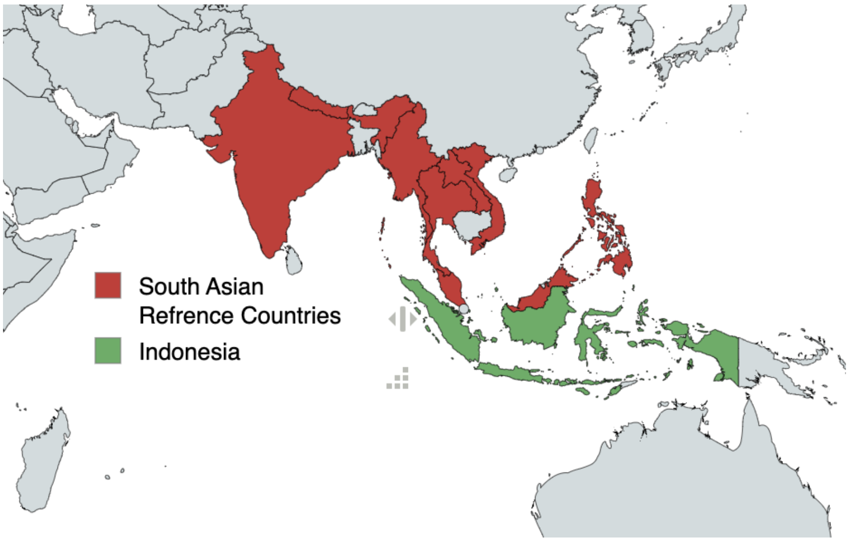

Figure 1: South Asian Reference Countries

3.1.1 Topology

The reference countries in this reference case share a similar topology. Like Indonesia, the reference countries have mountainous terrain with many mountains, hills, and abundant rivers, which is perfect for hydro power. However, the countries also share problems associated with this type of landscape. It is challenging to build in the mountainous terrain. As such, the aforementioned countries are relevant references because they share similar geographical advantages and disadvantages.

3.1.2 Culture

The reference countries also share cultural similarities with Indonesia. One of these is that large portions of the population live in rural areas (see Table 1).

Populations that live in rural areas are often dependent on rivers for their livelihood [9]. Installing hydropower can alter these rivers in a negative way for the rural communities. This is a challenge that all the reference countries share in installing new hydropower, which strengthens them as references for Indonesia.

Country	Rural Population (%)
Indonesia	41.43
India	63.64
Myanmar	67.89
Laos	61.75
Vietnam	60.52
Thailand	46.39
Nepal	78.10
Malaysia	21.28

Table 1: Rural Population Percentage in Reference Countries (2023) [8]

Another aspect of the influence of culture in the development of hydropower in the reference countries is the religious and spiritual significance of water. The development of hydropower must be done with respect for the populations' beliefs and traditions.

3.1.3 Governance

The governance of the reference countries is a vital point for ensuring equal comparison with Indonesia. Therefore, several governance indicators are considered for the proposed reference countries. The indicators are:

- **Government Effectiveness (GE)**
  Measurement of the quality of public services and policy formulation.
- **Rule of Law (RoL)**
  Confidence in laws and contract enforcement.
- **Control of Corruption (CoC)**
  Assessment of the degree of corruption.
- **Corruption Perceptions Index (CPI)**
  Perceived corruption.

The governance indicators for the reference countries are found in Table 2.

Country	GE (%)	RoL (%)	CoC (%)	CPI Score (/100)
Indonesia	69.8	46.7	36.3	34
India	67.9	56.1	41.5	39
Myanmar	3.8	6.1	11.8	20
Laos	28.3	22.6	19.8	28
Vietnam	56.1	50.5	38.7	41
Thailand	58.5	57.5	35.8	35
Nepal	21.7	34.9	34.0	35
Malaysia	79.7	67.5	61.8	50

Table 2: Governance Indicators for Reference Countries (2023) [10], [11]

The governance indicators of the reference countries are in the same ballpark for most of the reference cases, with Myanmar and Malaysia as outliers. The overall similarity of the governance indicators for the reference countries showcases the similarity in governance and strengthens them as reference countries.

3.2 Non-OECD Countries

Non-OECD is also selected as a reference case (see Figure 2). Non-OECD countries are emerging economies that are in the early to middle stages of their energy transitions [12], [13].

Non-OECD countries offer a more global perspective whilst still sharing some similarities in economy and governance. However, non-OECD countries are widely different in terms of geography and culture. The data from non-OECD countries is useful in capturing global trends in countries with somewhat similar economic and governance situations as Indonesia but should not be examined as closely as the data provided by more local reference countries.

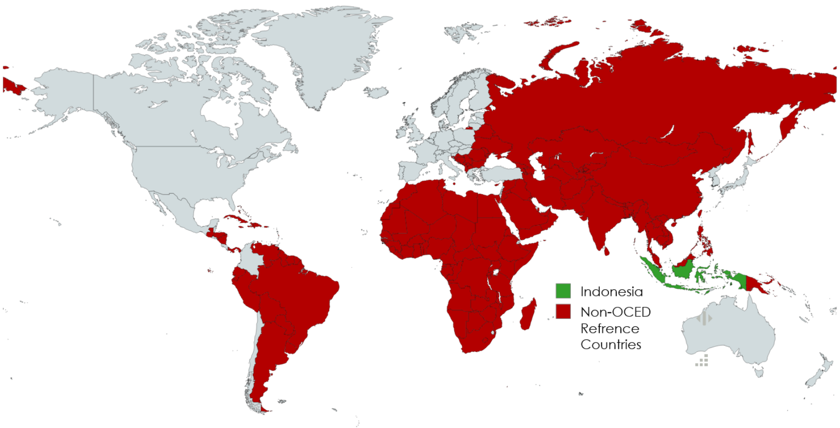

Figure 2: Non-OECD Reference Countries

4 Growth Metrics

The growth metric used to span the feasibility space is the aforementioned CAGR. One nice property of the CAGR is that even if a reference country is *not* in the acceleration phase of hydropower development, the CAGR can still be used on historical data [7]. The CAGR was calculated for each of the reference countries based on Irena data of installed capacity for each possible 15-year period, using a Python script (see Appendix 8.1) [6]. The calculated CAGR is only valid when a country has left the formative phase. In this feasibility assessment, a reference country is considered to be in the acceleration phase when it has an installed capacity of 500 MW of hydropower. Data from that point is used.

5 Feasibility Spaces

The feasibility spaces for both reference cases are based on the aforementioned growth metric CAGR. The resulting calculated CAGR values are used to construct feasibility spaces for the two cases in the following way:

5.1 South Asian Countries

For the higher quality, lower quantity reference case, the feasibility space is constructed by plotting all the subsequently calculated CAGRs. The calculated CAGR target for Indonesia is also plotted with a red dotted line. The results are observed in Figure 3.

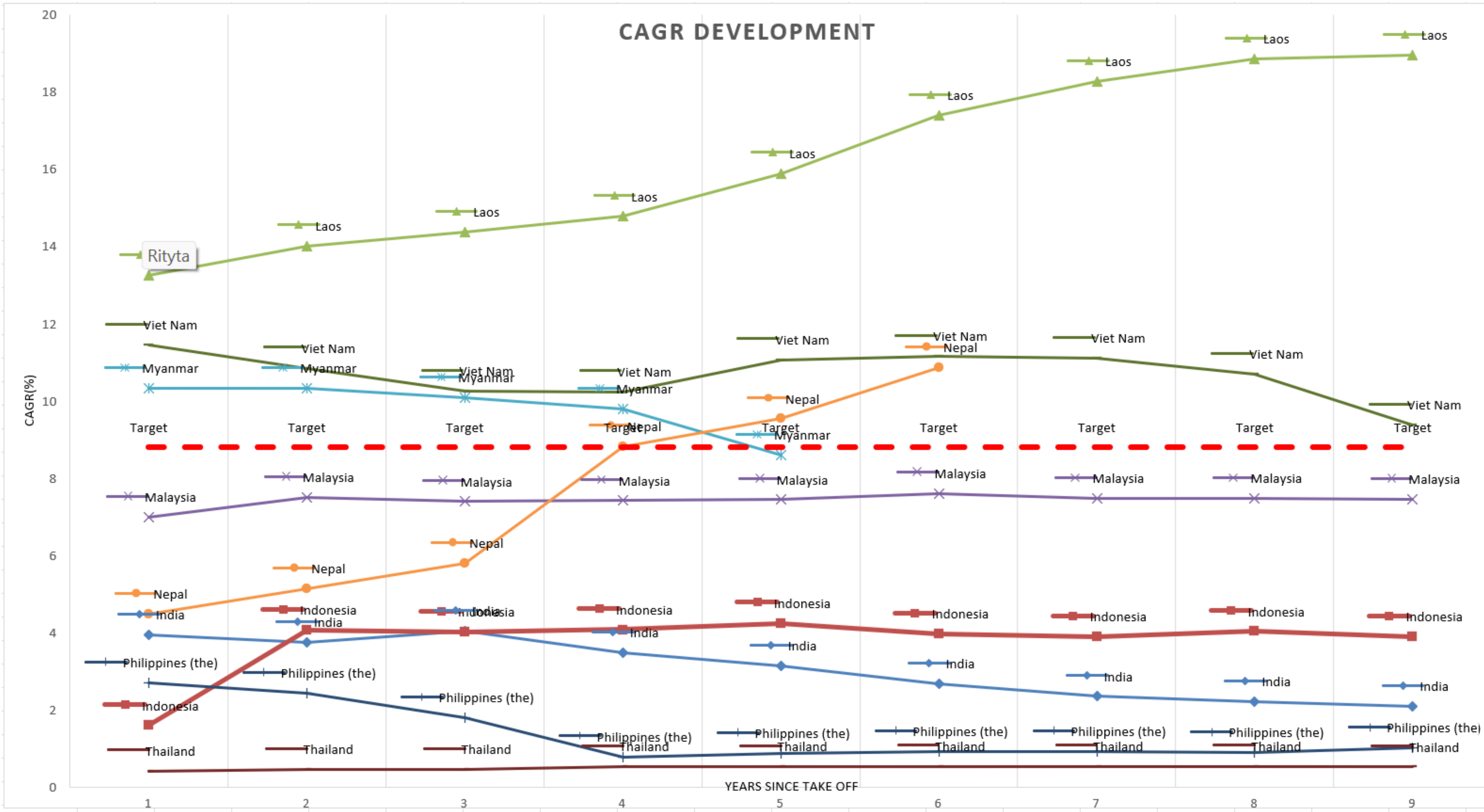

Figure 3: Feasibility Space for South Asian Reference Countries

From Figure 3 it can clearly be seen that the growth targeted by Indonesia has been achieved in the cases of Laos, Vietnam, Nepal, and Myanmar. It should, however, be noted that Indonesia's CAGR has not increased in the past years and that the current CAGR is half of the targeted growth. Also, the majority of the reference cases are below the target.

5.2 Non-OECD Countries

For the lower quality, higher quantity reference case, the feasibility space is constructed by the maximum CAGR calculated for each country. By the nature of this reference case (it consists of many countries), it is not reasonable to plot every country individually. Instead, for every country, an opaque area is plotted. The opaque areas plotted on top of each other generate the feasibility space where the darker areas represent more common CAGRs. The target CAGR is plotted on the shaded areas for comparison. This is done in a Python script (see Appendix 8.2). The resulting feasibility space is observed in Figure 4.

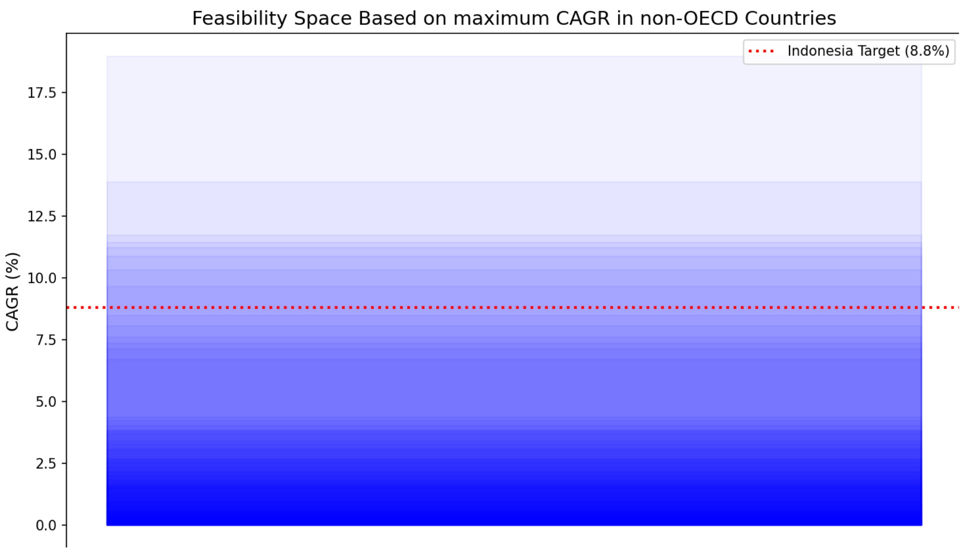

Figure 4: Feasibility Space for non-OECD Reference Countries

The resulting feasibility space showcases that the target growth has been achieved on several instances globally in non-OECD countries. It is also seen, however, that for most instances the *maximally* achieved CAGR is less than the target. Also, since the reference case is so diverse, it is not obvious that every instance can be directly compared to Indonesia.

6 Discussion

Both reference cases showcase that the CAGR Indonesia targets have been achieved. Albeit, most reference countries show CAGRs below the target. Further, Indonesia's current CAGR is half of what the targeted CAGR is. What this indicates for the targets' placement on the feasibility map depends on several factors.

6.1 Infrastructure

The current energy infrastructure in Indonesia needs development and expansion in order to accommodate the extra 25 GW of hydropower in the coming years [14]. The current challenges in infrastructure include outdated transmission lines and access to remote locations, locations where hydropower might be installed. Indonesia's ability to overcome these challenges affects the targets placement on the feasibility map.

6.2 Policy

Policy support is intrinsic to the reachability of the target. What is positive is that the target is set by the head of government in Indonesia. However, if there are no actual policies supporting the target the reachability suffers.

One actual policy support is in the form of a loan of USD 500 million to enable energy transition in Indonesia and develop a JETP investment and policy plan [15]. Another policy that supports renewable growth is the relaxation of the Local Content Rule [16]. The Local Content Rule states that a certain percentage of components in projects have to come from Indonesia. The easement of this rule provides more opportunity for foreign funding of renewable projects.

There is, however, a risk that the policies in place are not enough to reach the target. As of today, Indonesia has fallen short of past targets set for installed renewable capacity [17].

6.3 Hydropower Potential

Indonesia has, thanks to its topology, a high potential for hydropower. The potential for hydropower is estimated to be 75 GW [18]. This means that Indonesia only has to realize 42% of its hydro potential to reach the target.

7 Conclusion

The feasibility spaces spanned by the two different reference cases both showcase that the targeted growth is precedented. However, in both feasibility spaces, the majority of the reference countries have a CAGR lower than the target. It is discussed that the feasibility of the target is dependent on several factors. Indonesia has infrastructure challenges to overcome, which limits the feasibility of the target. Indonesia has several policies in place to expand its renewable energy. In spite of these policies, however, Indonesia has still fallen short of past targets. A positive note is that Indonesia has a very high hydro power potential, and that the realization of the target only represents a fraction of this potential.

Based upon the fact that the current CAGR in Indonesia is half of the targeted CAGR, and the challenges of infrastructure and past failures to meet the target, this results in the conclusion that Indonesia's target to install 25 GW capacity of hydro power in the next 15 years is **not feasible**. However, based on the precedences in both feasibility spaces of countries that have achieved the target, the target is **possible**. This is supported by the policies introduced that aid in the expansion of renewables in Indonesia. Ultimately, for the target to be feasible, more policies are likely to be required.

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8 Appendix

8.1 Code for CAGR Calculation

```python
import pandas as pd

# Replace this with the path to your actual Excel file
file_path = "CAp.xlsx"

# Define a function to calculate CAGR
def calculate_cagr(start_value, end_value, years):
    return ((end_value / start_value) ** (1 / years) - 1) * 100

# Function to process a reference case
def process_reference_case(sheet_name):
    # Load the data from the given sheet
    excel_data = pd.read_excel(file_path, sheet_name=sheet_name)

    # Initialize a list for the results
    results = []

    # Process data for each country
    unique_countries = excel_data['Country'].unique()  # Get unique
        country names
    for country in unique_countries:
        country_data = excel_data[excel_data['Country'] == country]  #
            Filter data for the country
        country_data = country_data.sort_values(by="Year")  # Ensure
            data is sorted by Year
        for i in range(len(country_data) - 15):
            start_value = country_data.iloc[i]['Capacity (MW)']
            # Check if the starting value is greater than 500 MW
            if start_value > 500:
                end_value = country_data.iloc[i + 15]['Capacity (MW)']
                start_year = country_data.iloc[i]['Year']
                end_year = country_data.iloc[i + 15]['Year']
                # Calculate CAGR
                cagr = calculate_cagr(start_value, end_value, end_year
                    - start_year)
                results.append({
                    "Country": country,
                    "Start Year": start_year,
                    "End Year": end_year,
                    "CAGR (%)": cagr
                })

    # Convert the results to a DataFrame and return
    return pd.DataFrame(results)

# Process both reference cases
results_ref1 = process_reference_case("Ref.1")
results_ref2 = process_reference_case("Ref.2")

# Save the results to a new Excel file with two sheets
output_file_path = "cagr_results.xlsx"
with pd.ExcelWriter(output_file_path, engine='openpyxl') as writer:
    results_ref1.to_excel(writer, sheet_name="Ref1 Results",
        index=False)
```

```
    results_ref2.to_excel(writer, sheet_name="Ref2 Results", index=False)

print(f"CAGR results saved to {output_file_path}")
```

8.2 Code for non-OECD Feasibility space

```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

# Load the results from Ref.2
file_path = "cagr_results.xlsx"  # Replace with your actual file path
results_ref2 = pd.read_excel(file_path, sheet_name="Ref2 Results")

# Extract unique countries and their maximum CAGR values
max_cagr_by_country = results_ref2.groupby("Country")["CAGR (%)"].max()

# Plot the feasibility space without gridlines
plt.figure(figsize=(10, 6))

# Create the shaded regions for each country's maximum CAGR
for idx, max_cagr in enumerate(max_cagr_by_country):
    x = np.array([0, 15])  # X-axis: arbitrary range of years for visualization
    y = np.array([max_cagr, max_cagr])  # Y-axis: max CAGR as a horizontal line
    plt.fill_between(x, 0, y, color="blue", alpha=0.05)  # Shaded area with low opacity

# Add the dotted red line for Indonesia's target
indonesia_target_cagr = 8.8  # Indonesia's target CAGR (%)
plt.axhline(y=indonesia_target_cagr, color="red", linestyle="dotted", linewidth=2, label="Indonesia Target (8.8%)")

# Add labels and legend
plt.title("Feasibility Space Based on maximum CAGR in non-OECD Countries", fontsize=14)

plt.ylabel("CAGR (%)", fontsize=12)
plt.legend()

# Show the plot
plt.tight_layout()
plt.show()
```