MSc ESDA Title Page

UCL Candidate Code: NQMJ9

Module Code: BENV0090

Module Title: Energy Systems

Coursework Title:
ASSESSING THE FEASIBILITY OF KENYA'S SOLAR POWER CAPACITY TARGETS

Module Leader: Prof. Neil Strachan

Date: 23/01/2025

Word Count: 1996

ASSESSING THE FEASIBILITY OF KENYA'S SOLAR POWER CAPACITY TARGETS

A Data Driven Twin Critique from Technological and Economic lenses

Introduction

The **"Legal Framework"** section of Kenya's latest Nationally Determined Contributions (NDC), states that the implementation of Kenya's NDC is to be done through Kenya's current and successive National Climate Change Action plans (NCCAPs) - (Government of Kenya, 2020).

As such, the specific target in this study is derived from Kenya's latest NCCAP III (2023-2027). Within this document, the following renewable energy targets are laid out:

589 MW new renewables developed by 30th June 2028 (Government of Kenya, 2023), including:

• Geothermal (208 MW), which is prioritised as baseload generation that is climate resilient.

• Solar - 174 MW.

• Wind - 161 MW.

The focus of this study is the **solar target** and the study's objective is thus:

> ***"To perform a data-driven twin critique of Kenya's target to develop 174 MW of newly installed solar capacity between 2023 (publication year of latest NCCAP) and 2028 (target year) from technological and economic lenses."***

Literature Review

Fig 1. shows that in 2023, solar energy in Kenya stood at only *3.9%* of total national electricity generation and Fig 2. further shows that solar generation in Kenya began in the early 2010s. (International Energy Agency (2024)

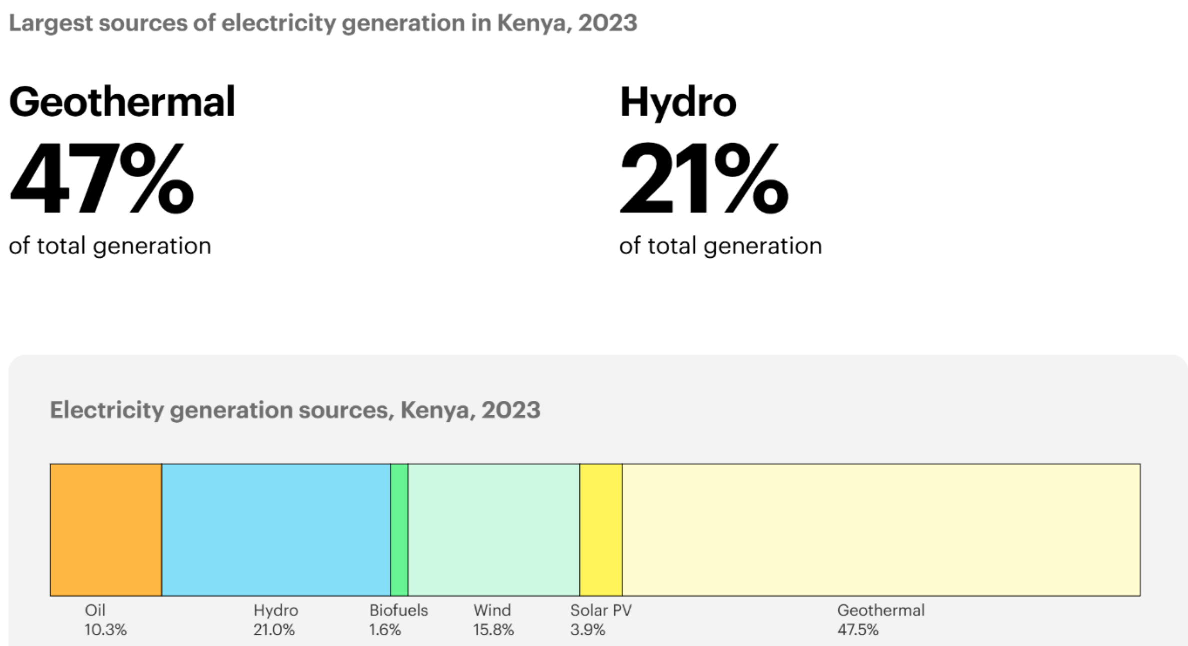

Figure 1: Kenya's energy generation mix in 2023

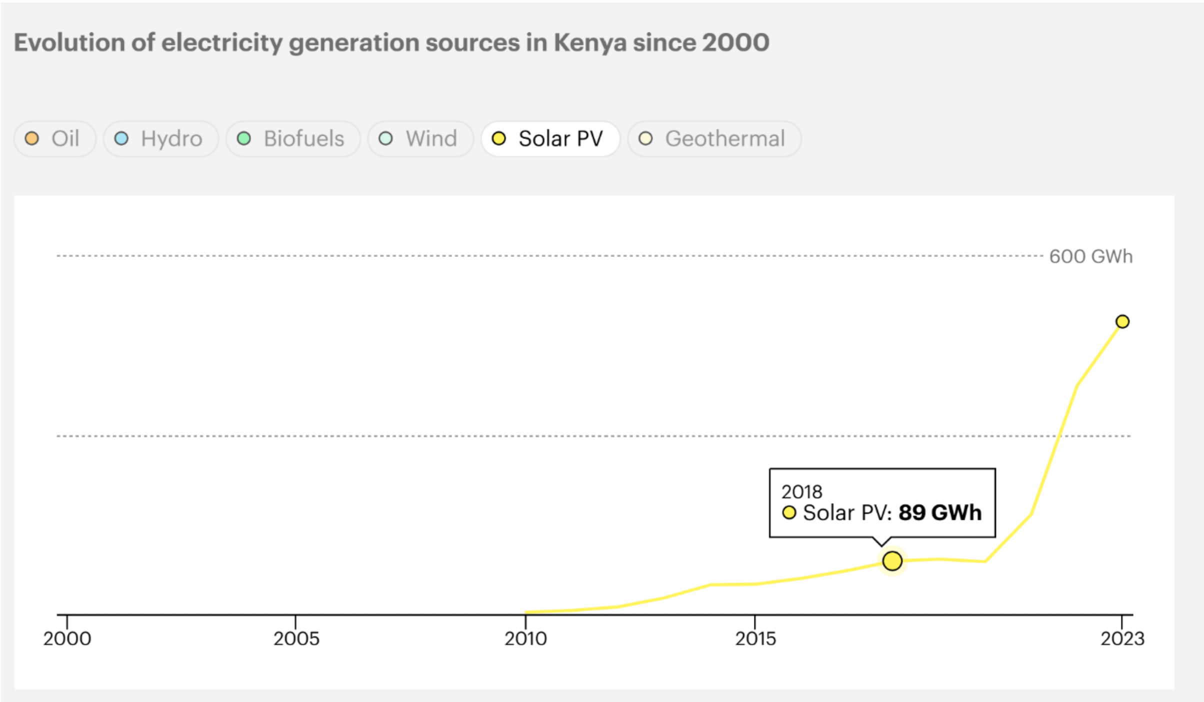

Figure 2: Evolution of Kenya's solar generation

To assess the feasibility of Kenya's target to install 174MW of new solar capacity between 2023 and 2028, a thorough review of the literature was carried out to establish the current context of Kenya's existing, in development and announced solar plants. Table 1 and Table 2 summarize the literature review findings on technological and economic data respectively.

Table 1: Kenya Solar Plants - Technological data summary

Project Name	Project foot print (Ha)	Capacity (MW)	Projected annual generation (MWh)	Status	References
Eldosol Cedata solar	121	48	74,968	operating	Renewables Now, 2017; Frontier Energy (n.d.)
Garissa solar	85	55	76,473	operating	Business Daily, 2018; Power Technology, 2024
Alten Kesses I solar	10	55	123,600	operating	Alten Energy (n.d.); Power Technology, 2024
Malindi solar	263	52	-	operating	Power Technology, 2024
Radiant solar	121	48	74968	operating	Renewables Now, 2018; Frontier Energy (n.d.)
Kisumu solar	100	40	103,000	construction	SolarQuarter, 2023
Seven Forks solar	-	42.5	102,700	construction	Agence Française de Développement (AFD) (n.d.)
Kabariange solar	-	90	-	pre-construction	Global Energy Monitor, 2024
Alten Kesses II solar	-	55	-	pre-construction	Power Technology, 2024
Lamu Kensen solar	40	40	-	pre-construction	Sigma Plantfinder (n.d.)
Siaya County solar		40	-	pre-construction	Kawi Hub, 2024
Voltalia Kopere solar	158	50	-	pre-construction	Construction Kenya, 2022 Nation Media Group, 2018
HDF Green Hydrogen Solar	-	180	-	Announced	Power Technology, 2024
Bavinci Africa Solar	-	70	-	Announced	Power Technology, 2024
Nyeri solar	-	40	-	cancelled	Global Energy Monitor, 2024
Isiolo solar	-	40	-	cancelled - inferred 4 y	Global Energy Monitor, 2024
Kitui solar	-	40	99,275	cancelled - inferred 4 y	Power Technology, 2024
Rumuruti solar	121	40	-	shelved	Construction Review Online, 2021; Business Daily Africa, 2018

Table 2: Kenya Solar Plants - Economic data summary - same references apply as technological data

Project Name	Project Budget (M USD)	Construction Start Date	Operation Start Date	Electricity Price ($/kWh)	Owner / Developer
Eldosol Cedata solar	78	01/01/2019	01/08/2021	0.12	Frontier Investment Management APS; Cedate LTD; Selenkei Investment LTD; Paramount Universal Bank
Garissa solar	136	01/01/2017	13/12/2019	0.054	Rural Energy Authority of Kenya
Alten Kesses I solar	87	01/01/2020	01/06/2023	-	Alten Energías Renovables
Malindi solar	69	01/01/2019	14/12/2021		Africa Energy Development CORP ; Globeleq Generation Ltd
Radiant solar	78	01/01/2019	01/08/2021	0.12	Frontier Investment Management APS; Cedate LTD; Selenkei Investment LTD; Paramount Universal Bank
Kisumu solar	52	01/08/2022	01/01/2024	0.0575	Ergon Solair
Seven Forks solar	62	01/06/2024	01/06/2026	-	Kenya Electricity Generating Company PLC
Kabariange solar	124	01/09/2017		-	Midlands Solar
Alten Kesses II solar	-			-	Alten Energías Renovables
Lamu Kensen solar	-	01/09/2016	01/01/2024	-	Kenya Solar Energy LTD
Siaya County solar	70	01/01/2018	01/12/2024	-	Xago Africa
Voltalia Kopere solar	64	01/01/2016	01/01/2024	0.08	Voltalia SA
HDF Green Hydrogen Solar	500	01/01/2025	01/01/2027	-	-
Bavinci Africa Solar	-	01/01/2025	01/01/2026	-	-
Nyeri solar	-	-	-	-	Kumar and Associates
Isiolo solar	-	-	-	-	Greenmillenia Energy
Kitui solar	-	01/01/2024	01/01/2025	0.12	Looop INC
Rumuruti solar	58.7	-	-	0.08	Kenergy Renewable

Methodology and Results

A) TECHNOLOGICAL ANALYSIS

1) GIS-Based Analysis of Kenya's solar resource potential

From Tables 1 and 2, the total sum of installed solar capacity in Kenya that was *operational by 2023* was **248 MW,** meaning that if Kenya was to meet her target of **174 MW** of new solar capacity by 2028 the total installed solar capacity would be **422 MW** in 2028**.**

Using the projected annual generation and installed capacities for existing plants in Table 1, the operational solar plants in Kenya operate with an average capacity factor (C.F.) of **0.19**.

$$C.F. = \frac{Projected\ Annual\ Generation\ (MWh)}{Plant\ Capacity(MW) * 365 * 24}$$

Assuming this C.F. holds true in 2028, the total annual solar generation in 2028 would be:

$$422\ MW * 0.19 * 365 * 24 \sim \mathbf{700\ GWh}$$

To determine whether Kenya has the solar resource potential to meet this target, data on the average solar surface radiation downwards (SSRD) received in Kenya for the year 2024 was obtained from the dataset *"ERA5 hourly data on single levels from 1940 to present"* in the climate data store (Copernicus Climate Change Service (C3S), 2025).

The SSRD was plotted as a raster file with a resolution of 1km^2 to match the average footprint of existing solar plants (100 Ha) as seen in Table1.

For each cell, the SSRD was converted to energy potential in GWh as given by (Saur Energy, 2023):

$$E = \frac{G * A * r * pr}{3600 * 10^6}$$

Where,

E = energy output of solar panels (GWh)

G = SSRD (J/m^2)

A = Area of solar panels (m^2) = 1km^2

r = Solar Panel efficiency (%) -typically = **21%** (*University of Michigan. (n.d.)*)

pr = Performance ratio of system. (%) – typically = **78%** (*U.S. Department of Energy, 2022)*

GIS Results

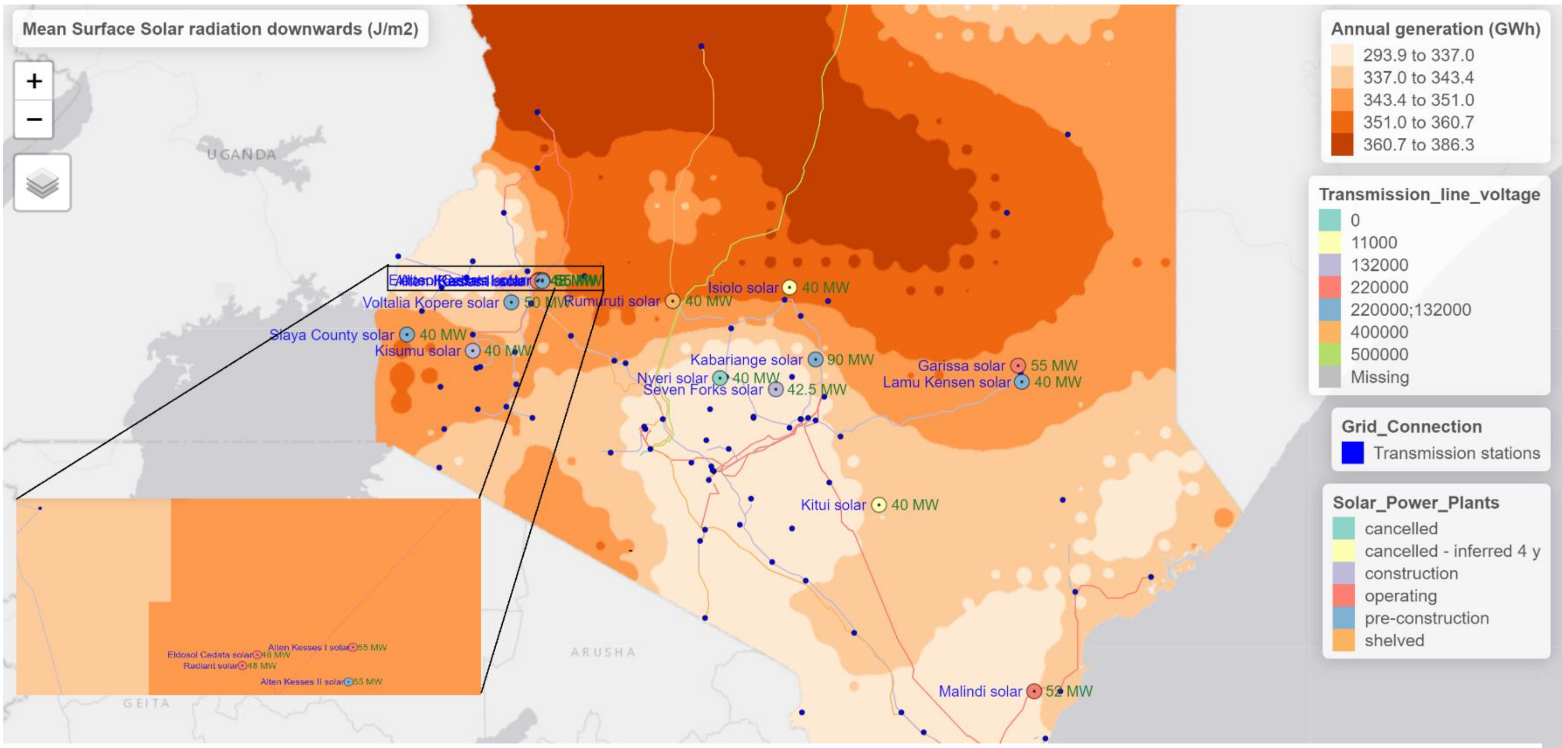

Figure 3: Kenya's Solar Resource Potential in 2024

As seen in Fig. 3, assuming similar SSRD levels in 2028 as in 2024, Kenya can easily meet the target of **700 GWh** annual solar generation by 2028 from a natural resource potential point of view as there are numerous geographical sites (1km^2 grid cells) with an annual generation potential above **200 GWh**.

2) Installed Solar Capacity analysis

The historical trend of solar capacity installation was extrapolated to determine whether the target of **422 MW** total solar capacity (174 MW newly installed after 2023) would be met in 2028. The cumulative installed capacity between 2019-2023 was computed from the data in Table 1 and used to fit prediction models.

For simplicity, linear regression was used to predict future solar capacity. However, adoption of new technologies often follows non-linear patterns (Bass, F.M., 1969) and innovation and cost reductions drive non-linear adoption trends in solar PV (Kavlak, G. et. Al.,2018). As such, polynomial regression (2nd degree) was also employed to capture the non-linear aspects of solar capacity growth.

Fig. 4 and Fig. 5 show the linear and polynomial regression results respectively.

Extrapolation Results

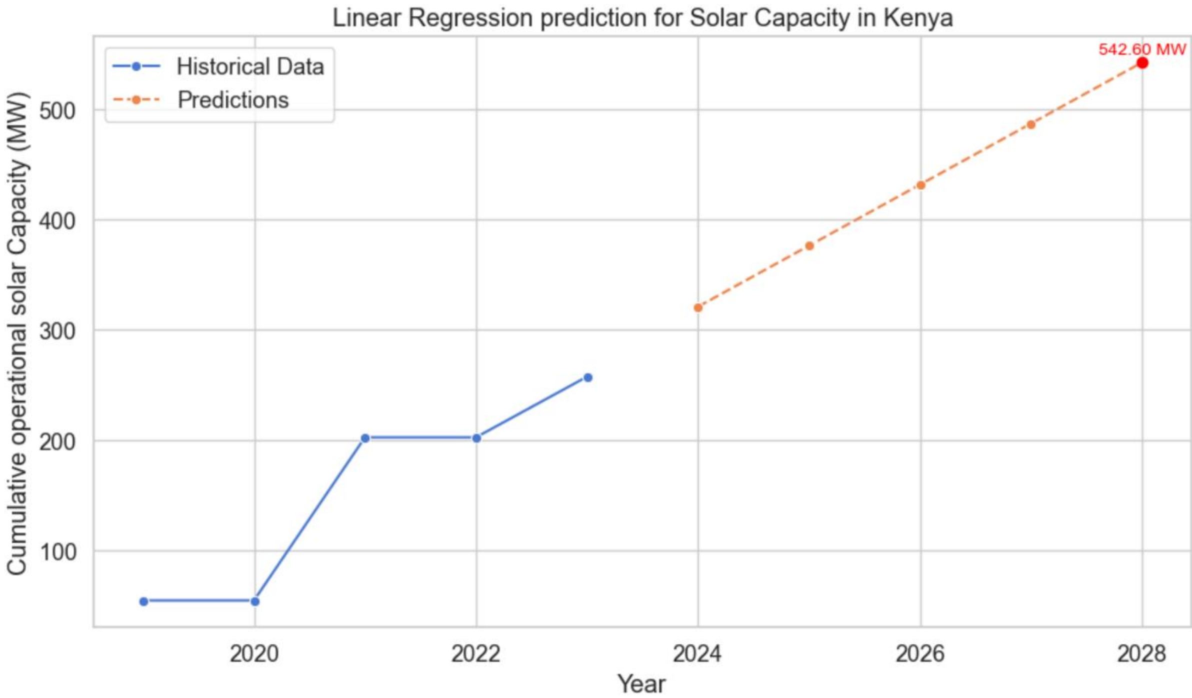

Figure 4: Linear regression extrapolation of solar capacity in Kenya

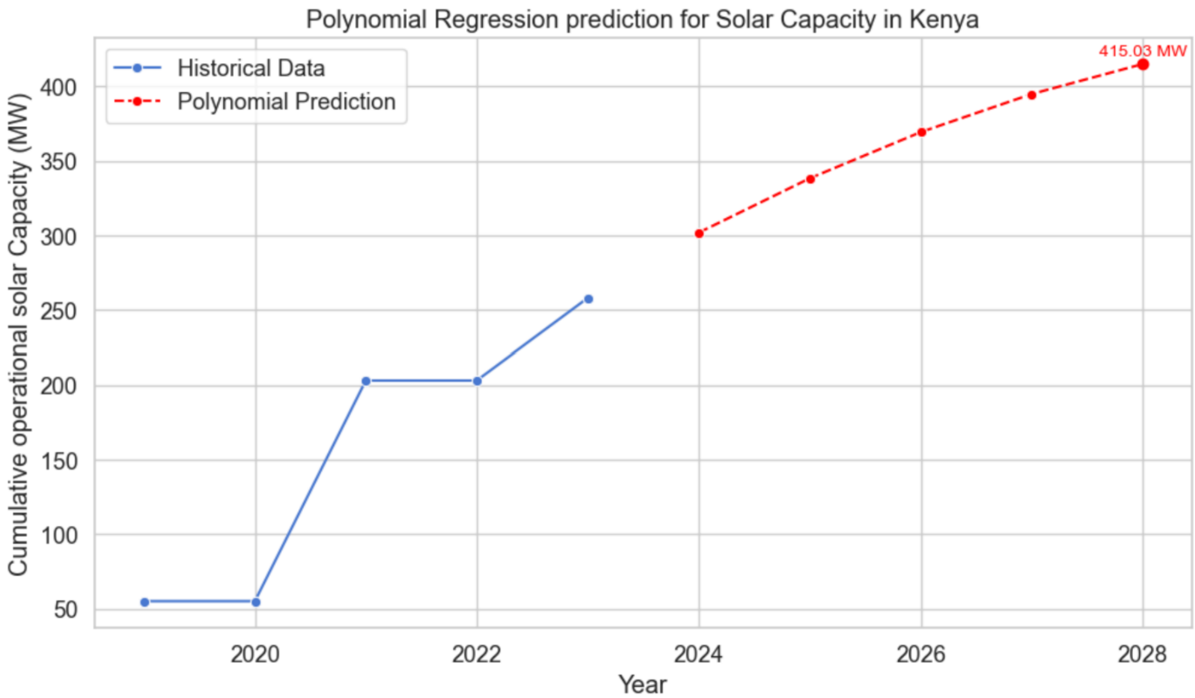

Figure 5: Polynomial regression extrapolation of solar capacity in Kenya

Under both regression extrapolations, Kenya is able to just about meet the target of **422 MW** total solar capacity in 2028 with **542 MW** predicted under the linear regression model and **415 MW** predicted under the polynomial model. This indicates that based on historical solar capacity additions, Kenya has sufficient technological capacity and solar expertise in the form of contractors and developers and is therefore on track to meet the target of **422 MW** by 2028.

3) IEA solar generation prediction

Similarly to installed solar capacity, solar generation was also extrapolated to determine whether the derived annual solar generation target of **700 GWh** would be met in 2028. Data on historical solar generation in Kenya as seen in Fig. 2 was obtained from IEA (International Energy Agency (2024).

Fig. 6 and Fig. 7 show the linear and polynomial regression results respectively.

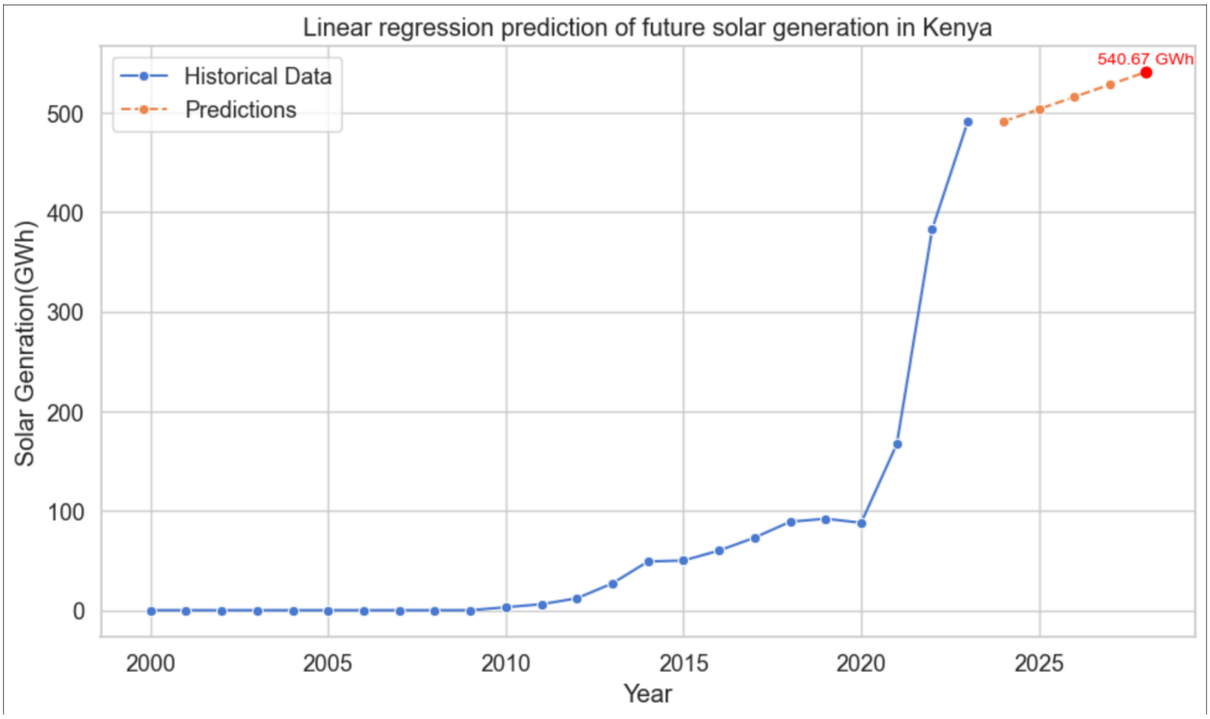

Figure 6: Linear regression extrapolation of solar generation in Kenya

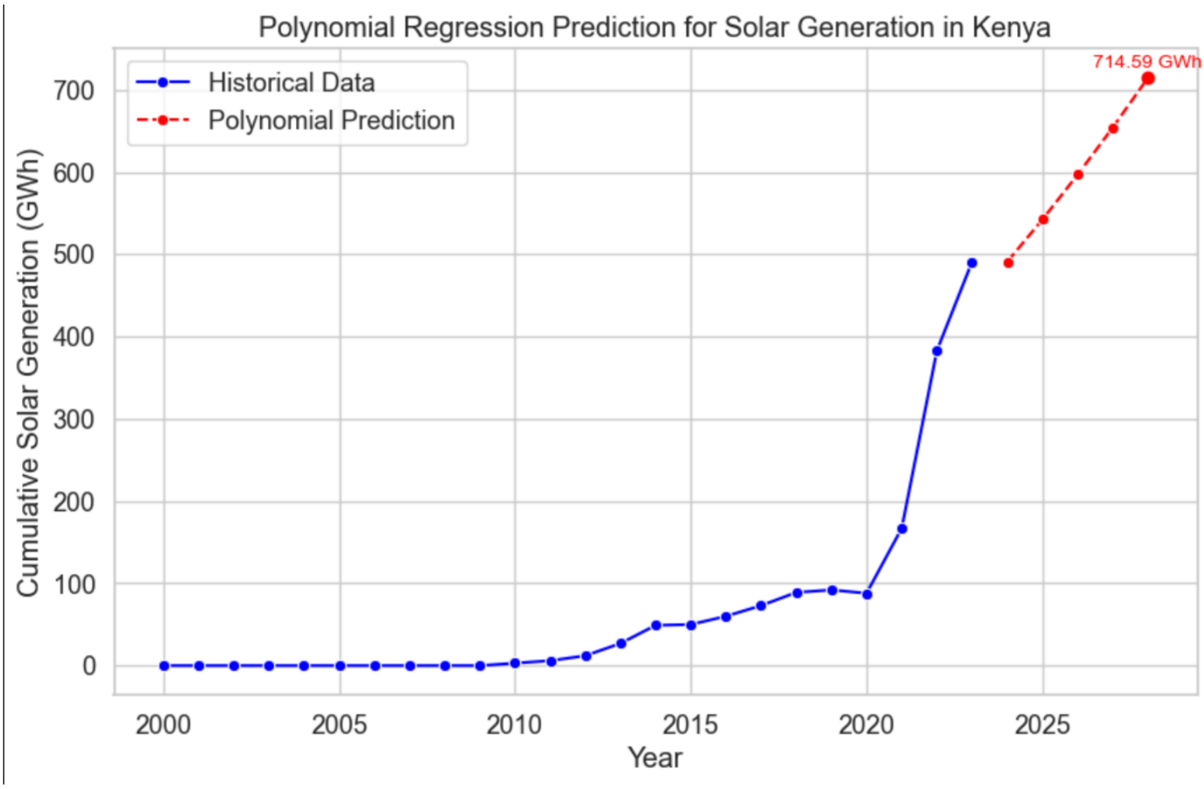

Figure 7: Polynomial regression extrapolation of solar generation in Kenya

As expected, under the linear regression, Kenya falls short of the target of **700 GWh** in 2028 with a predicted output of **540 GWh**. The linear regression fails to account for non-linearities in solar adoption such as the spike in added capacity witnessed between 2021-2022. The polynomial regression accounts for such non-linearities and the predicted output of **714 GWh** in 2028 under this model means Kenya will meet the solar generation target.

B) ECONOMIC ANALYSIS

From Table 1, the development time for each plant was computed as the difference between the operation start dates and construction start dates.

Thus, assuming the projects budgets were evenly spread over their development times, the average historical per year capital investment rate for operational solar plants was calculated as:

$$Per\ year\ Investment\ Rate = \ Average\left(\frac{budget}{development\ time}\right) = \mathbf{31.09}\ M\ USD/yr$$

Similarly, the average historical per MW investment rate was computed as:

$$Per\ MW\ Investment\ Rate = \ Average\left(\frac{budget}{Capacity}\right) = \mathbf{1.73}\ M\ USD/MW$$

Using the historical per MW investment rate, the cost of the targeted 174 MW new capacity was calculated as:

$$Projected\ Cost = \ Per\ MW\ Investment\ Rate * 174\ = 1.73M * 174 = \mathbf{300.38}\ M\ USD$$

Assuming the solar capacity target is met within the specified time period (2023-2028) i.e. 5 years, the new per year investment rate was computed as:

$$New\ Per\ year\ Investment\ Rate = \frac{Projected\ Cost}{5} = \frac{300.38}{5} = \mathbf{60.08}\ M\ USD/yr$$

Compared to the historical per year investment rate of **31.09 M USD/YR** (between 2019-2023), this result shows that between 2023-2028, Kenya would need to **double** the per year investment rate in utility scale solar plants if she is to meet the target of 174 MW new solar capacity. As earlier mentioned, reduction in solar PV manufacturing costs could reduce the per MW investment rate, however the doubling of per year investment rate (calculated with historical per MW rates) indicates that reduced PV manufacturing costs alone may not be enough to offset the high investments required to meet the target by 2028.

Table 3 shows the results of the historical investment rates for existing operational plants.

Table 3: Investment Rates Summary

Project Name	Capacity (MW)	Project Budget (M USD)	Construction Start Date	Operation Start Date	Development time (yrs)	Per MW investment (M USD/MW)	Per yr investment (M USD/yr)
Eldosol Cedata solar	48	78	01/01/2019	01/08/2021	2.58	1.63	30.21
Garissa solar	55	136	01/01/2017	13/12/2019	2.95	2.47	46.17
Alten Kesses I solar	55	87	01/01/2020	01/06/2023	3.41	1.58	25.48
Malindi solar	52	69	01/01/2019	14/12/2021	2.95	1.33	23.38
Radiant solar	48	78	01/01/2019	01/08/2021	2.58	1.63	30.21
					AVERAGE	**1.73**	**31.09**

Discussion and Conclusions

The study's objective was to assess the feasibility of Kenya's target to install **174 MW new solar capacity** between **2023** and **2028** from *technological* and *economic* lenses. From a resource potential point of view, Kenya easily meets the derived target of 700 GWh annual generation by 2028 due to high levels of SSRD received.

The regression extrapolations for installed capacity and solar generation signify that historical capacity additions demonstrate an upward trend and technological capacity required to meet the target.

Economic analysis however revealed that the target may be too ambitious as it requires a doubling in the capital investment rate per year over the five years.

To arrive at a definitive conclusion on whether the target may or may not be met, future work should analyze in-depth development reports including bills of quantities for planned and in-construction solar plants to establish whether the per MW cost of installation is reduced compared to historical rates. Future work should also determine verifiable power purchase agreements that have been proposed by Kenya's ministry of energy. Higher feed-in tariffs may mean investors have a higher risk appetite due to shorter payback times whereas lower feed in tariffs may deter further investments in utility scale solar capacity installation.

References

Government of Kenya, 2020. *Kenya's First NDC (updated version)*. [online] UNFCCC. Available at: https://unfccc.int/sites/default/files/NDC/2022-06/Kenya%27s%20First%20%20NDC%20%28updated%20version%29.pdf [Accessed 11 January 2025].

Construction Review Online, 2018. *Kenyan firms get US $75m funding for solar power plants projects*. [online] Construction Review Online. Available at: https://constructionreviewonline.com/news/kenya/kenyan-firms-get-us-75m-funding-solar-power-plants-projects/ [Accessed 11 January 2025].

Government of Kenya (2023). *National Climate Change Action Plan (Kenya) 2023-2027*. Ministry of Environment, Climate Change and Forestry, Nairobi, Kenya.

International Energy Agency, 2024. *Kenya: Electricity*. [online] International Energy Agency. Available at: https://www.iea.org/countries/kenya/electricity [Accessed 11 January 2025].

Ministry of Energy (2010) *Kenya's Feed-in-Tariffs Policy on Renewable Energy Resource Generated Electricity (Small Hydro, Biomass and Biogas)*. Available at: https://communications.bowmanslaw.com/REACTION/emsdocuments/fitPolicy.pdf?utm_source=chatgpt.com (Accessed: 18 January 2025).

International Energy Agency (IEA) (2024) *Revised feed-in tariffs for renewable energy*. Available at: https://www.iea.org/policies/4957-revised-feed-in-tariffs-for-renewable-energy? (Accessed: 18 January 2025)

Business Daily (2018) *Garissa 55MW solar farm starts operations*. Available at: https://www.businessdailyafrica.com/economy/Garissa-55MW-solar-farm-starts-operations/3946234-4315276-g2qldpz/index.html (Accessed: 18 January 2025).

Power Technology (2024) *Power plant profile: Garissa Solar Park, Kenya*. Available at: https://www.power-technology.com/marketdata/power-plant-profile-garissa-solar-park-kenya/ (Accessed: 18 January 2025).

Power Technology (2024) *Power plant profile: Kesses 1 Solar PV Park, Kenya*. Available at: https://www.power-technology.com/data-insights/power-plant-profile-kesses-1-solar-pv-park-kenya/ (Accessed: 18 January 2025).

Power Technology (n.d.) *Power plant profile: Kesses 2 Solar PV Park, Kenya*. Available at: https://www.power-technology.com/marketdata/power-plant-profile-kesses-2-solar-pv-park-kenya/t (Accessed: 18 January 2025).

Power Technology (2024) *Power plant profile: Malindi Solar PV Park, Kenya*. Available at: https://www.power-technology.com/data-insights/power-plant-profile-malindi-solar-pv-park-kenya/ (Accessed: 18 January 2025).

Power Technology (2024) *HDF Green Hydrogen Solar PV Project, Kenya*. Available at: https://www.power-technology.com/data-insights/power-plant-profile-hdf-green-hydrogen-solar-pv-project-kenya/ (Accessed: 18 January 2025).

Frontier Energy (n.d.) *Eldosol Solar PV Project, Kenya*. Available at: https://frontier.dk/eldosol-solar-pv-project-kenya/ (Accessed: 18 January 2025).

Frontier Energy (n.d.) *Radiant Solar PV Project, Kenya*. Available at: https://frontier.dk/radiant-solar-pv-project-kenya/ (Accessed: 18 January 2025).

Globeleq (n.d.) *Globeleq's Malindi Solar Plant is generating clean energy to the national grid*. Available at: https://globeleq.com/globeleqs-malindi-solar-plant-is-generating-clean-energy-to-the-national-grid/ (Accessed: 18 January 2025).

Renewables Now (2017) *Three investors advance 120 MW solar power projects in Kenya*. Available at: https://renewablesnow.com/news/three-investors-advance-120-mw-solar-power-projects-in-kenya-544721/ (Accessed: 18 January 2025).

Renewables Now (2018) *Three investors advance 120 MW solar power projects in Kenya*. Available at: https://renewablesnow.com/news/three-investors-advance-120-mw-solar-power-projects-in-kenya-544721/ (Accessed: 18 January 2025).

Alten Energy (n.d.) *Kenya Eldoret*. Available at: https://alten-energy.com/projects/africa/kenya-eldoret/ (Accessed: 18 January 2025).

SolarQuarter (2023) *Kisumu Solar One: Kenya's 40 MW solar project to commence operation in 2024*. Available at: https://solarquarter.com/2023/03/24/kisumu-solar-one-kenyas-40-mw-solar-project-to-commence-operation-in-2024/ (Accessed: 18 January 2025).

Sigma Plantfinder (n.d.) *Plans to construct a 40MW solar power plant in Kenya underway*. Available at: https://www.sigmaplantfinder.com/blog/plans-to-construct-a-40mw-solar-power-plant-in-kenya-underway/ (Accessed: 18 January 2025).

Agence Française de Développement (AFD) (n.d.) *Kenya: Seven Forks power plant*. Available at: https://www.afd.fr/en/carte-des-projets/kenya-seven-forks-power-plant (Accessed: 18 January 2025).

Kawi Hub (2024) *Obama-backed solar project set for 2024*. Available at: https://kawihub.com/obama-backed-solar-project-set-for-2024/ (Accessed: 18 January 2025).

Construction Kenya (2022) *Kopere solar power project*. Available at: https://www.constructionkenya.com/2762/kopere-solar-power-project/ (Accessed: 18 January 2025).

Nation Media Group (2018) *French firm inks 50MW solar electricity deal*. Available at: https://nation.africa/kenya/business/French-firm-inks-50MW-solar-electricity-/996-4582920-9ednj4z/index.html (Accessed: 18 January 2025).

Construction Review Online (2021) *Kenya to construct 40MW solar power plant in Laikipia County*. Available at: https://constructionreviewonline.com/news/kenya/kenya-to-construct-40mw-solar-power-plant-in-laikipia-county/ (Accessed: 18 January 2025).

Business Daily Africa (2018) *Solar firm to sell 40MW from Sh6bn Laikipia unit*. Business Daily Africa. Available at: https://www.businessdailyafrica.com/markets/marketnews/Solar-firm-to-sell-40MW-from-Sh6bn-Laikipia-unit/3815534-4612828-kg5hnq/index.html (Accessed: 18 January 2025).

Global Energy Monitor (2024) *Kabariange solar farm*. Available at: https://www.gem.wiki/Kabariange_solar_farm (Accessed: 18 January 2025).

Global Energy Monitor (2024) *Nyeri solar farm*. Available at: https://www.gem.wiki/Nyeri_solar_farm (Accessed: 18 January 2025).

Global Energy Monitor (2024) *Isiolo solar farm*. Available at: https://www.gem.wiki/Isiolo_solar_farm (Accessed: 18 January 2025).

Saur Energy, 2023. *Here is how you can calculate the annual solar energy output of a photovoltaic system*. [online] Available at: https://www.saurenergy.com/solar-energy-blog/here-is-how-you-can-calculate-the-annual-solar-energy-output-of-a-photovoltaic-system [Accessed 20 January 2025].

U.S. Department of Energy, 2022. *Understanding solar photovoltaic system performance*. [online] Available at: https://www.energy.gov/sites/default/files/2022-02/understanding-solar-photo-voltaic-system-performance.pdf [Accessed 20 January 2025].

University of Michigan. (n.d.). *Solar PV energy factsheet*. Center for Sustainable Systems. Available at: https://css.umich.edu/publications/factsheets/energy/solar-pv-energy-factsheet?utm_source=chatgpt.com [Accessed 20 January 2025].

Bass, F.M., 1969. A new product growth model for consumer durables. *Management Science*, 15(5), pp.215–227. Available at: https://pdodds.w3.uvm.edu/files/papers/others/1969/bass1969a.pdf [Accessed 21 January 2025].

Kavlak, G., McNerney, J. and Trancik, J.E. (2018) 'Evaluating the causes of cost reduction in photovoltaic modules', *Energy Policy*, 123, pp. 700–710. Available at: https://dspace.mit.edu/bitstream/handle/1721.1/123492/SSRN-id2891516.pdf (Accessed: 21 January 2025).

Copernicus Climate Change Service (C3S) (2025) ERA5: Reanalysis data on single levels. Available at: https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview (Accessed: 21 January 2025).