ASSESSING SUSTAINABLE DEVELOPMENT GOALS USING SATELLITE IMAGERY AND MACHINE LEARNING

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Introduction

In 2015, the UN introduced 17 Sustainable Development Goals (SDGs) under the 2030 Agenda. Limited data coverage hinders progress tracking, prompting the use of satellite imagery and machine learning to fill information gaps, particularly for infrastructure-related SDGs. The Model Supply Region (MSR) framework (Sterl et al., 2022) identifies Africa's optimal renewable zones based on resource, cost, and grid factors. However, its validity remains untested. This study validates MSRs against real solar and wind projects using TZ-SAM satellite detections, assessing spatial alignment between modeled regions and actual installations. The results enhance confidence in MSR modeling and support data-driven planning for SDG 7.B.1 on renewable energy capacity in developing countries.

1. To what extent do existing and planned renewable energy projects align spatially with MSR-defined optimal zones?
2. How do proximity to transmission infrastructure and grid accessibility affect this alignment?
3. Which high-potential MSRs remain underutilized due to limited infrastructure or investment?

Methodology

This study assesses how Africa's existing and planned solar infrastructure aligns with optimal renewable energy zones (MSRs) identified by *Sterl et al.* It integrates open geospatial datasets and spatial analysis methods to quantify overlap and proximity between real-world solar assets and theoretically optimal regions.

1. Data sources

- Africa Energy Tracker (AET):
  - Includes operational and planned renewable projects.
  - Solar PV ≥ 1 MW; Wind ≥ 10 MW.
  - Contains project status and generation capacities.
- TZ-SAM Dataset:
  - Provides verified PV locations and capacities using CV models with manual validation.
- World Bank Electricity Grid Map:
  - Comprehensive open-source map of Africa's transmission and distribution network.
- Model Supply Regions (MSRs, Sterl et al. 2022):
  - Define optimal renewable zones based on resource availability, LCOE, land constraints, and grid distance.
  - Used as the benchmark for "theoretically optimal" solar siting.

2. Spatial Analysis and Overlay Procedures

- Conducted in QGIS, standardized to WGS 84.
- 10 km buffer applied to MSR polygons to include assets near boundaries.
- Overlap analysis: quantified count and total capacity of PV plants within buffered MSRs relative to Africa's total.
- Separate evaluations for:
  - Operational installations.
  - Non-operational (planned or under construction) projects from AET.

3. Additional Geospatial Computations

To complement the overlap assessment, additional distance-based analyses were conducted:

- Proximity to MSRs: For PV plants outside MSRs, computed Euclidean distance to nearest MSR centroid to assess spatial displacement using MSR nearest centroid coordinates (x_{c_j}, y_{c_j}) .

$$D_i^{\text{MSR}} = \min_{j \in J} \sqrt{(x_i - x_{c_j})^2 + (y_i - y_{c_j})^2}$$

- Proximity to transmission lines: Measured shortest (perpendicular or endpoint) distance from each PV plant iii to nearest transmission line $L(k)$ in set K.

$$D_i^{\text{Grid}} = \min_{k \in K} d\big((x_i, y_i), L_k\big)$$

- MSR Characteristics: Calculated descriptive stats for MSRs with ≥1 solar installation: mean capacity, area, grid distance, LCOE, and CF.

$$\overline{X}_{\text{MSR}} = \frac{1}{M} \sum_{m=1}^{M} X_m$$

4. Analytical Framework:

- Overlap: Measure spatial coincidence between PV installations and MSRs.
- Accessibility: Compute average distances to nearest MSR and transmission line.
- Stranded Potential: Identify MSRs with high yield (low LCOE, high CF) but poor grid access.

Visualizations

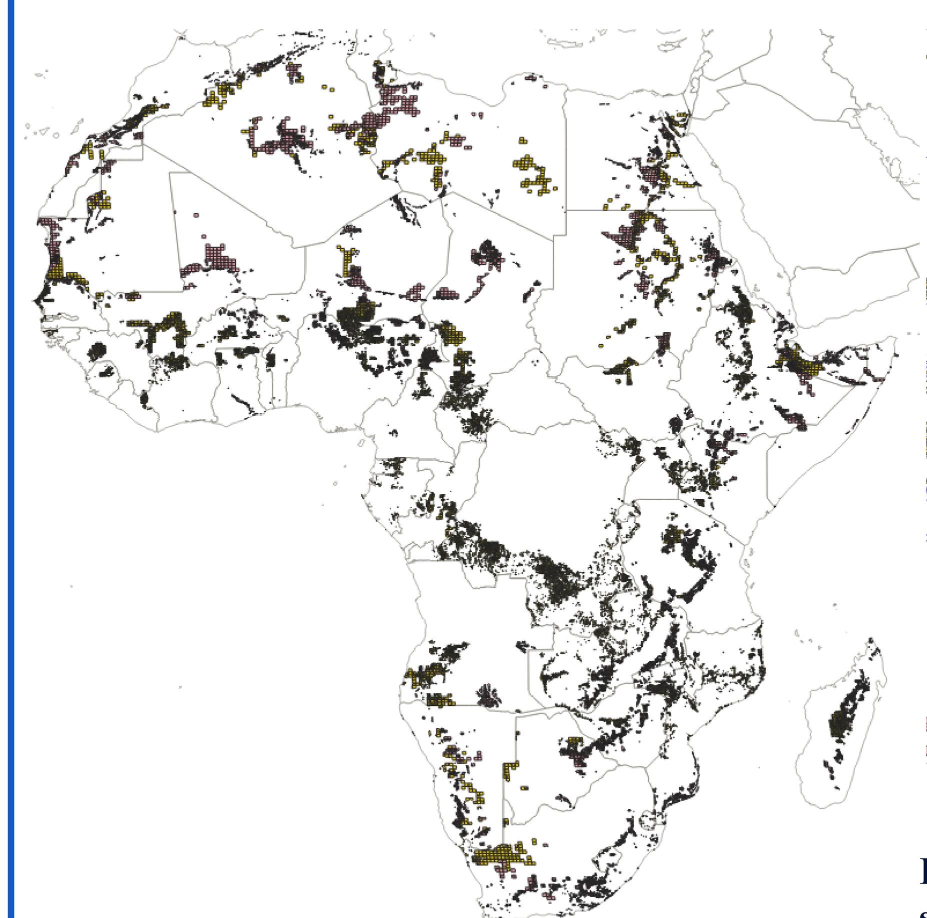


Fig 1. Visualization of Solar and Wind Model Supply Regions across continent of Africa.

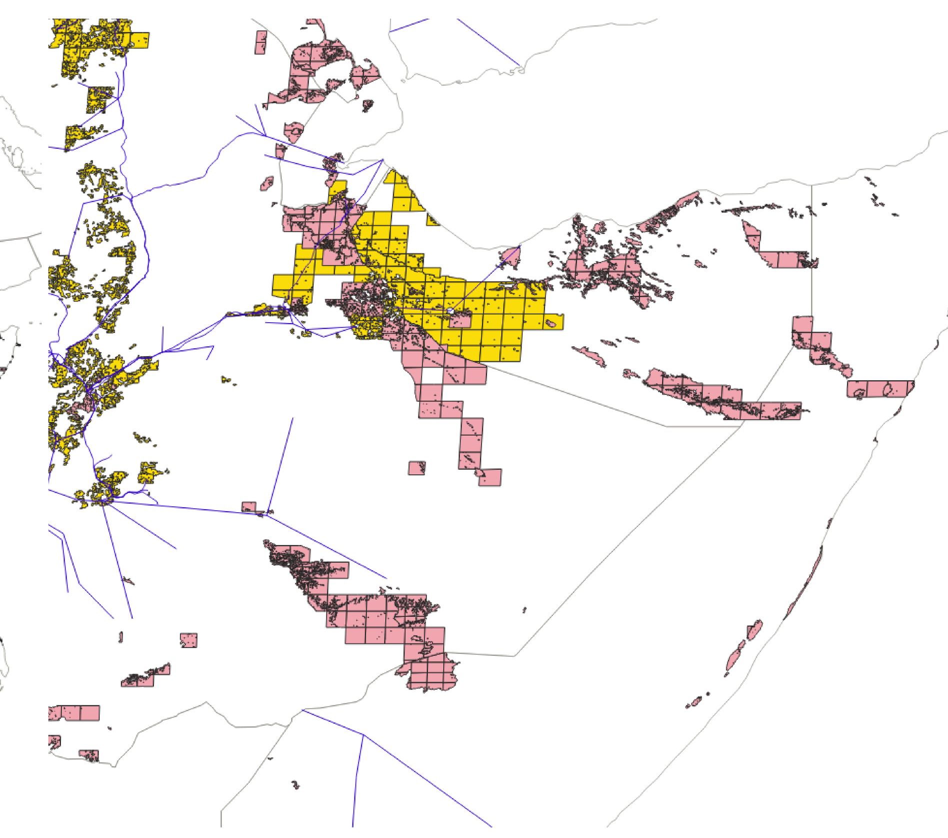


Fig 2. Zoom-in look into MSR regions across Africa, spcifically Horn of Africa. Yellow shapefiles represent Solar PV MSRs, pink shapefiles represent Wind MSRs, and blue lines represent Africa Transmission grid.

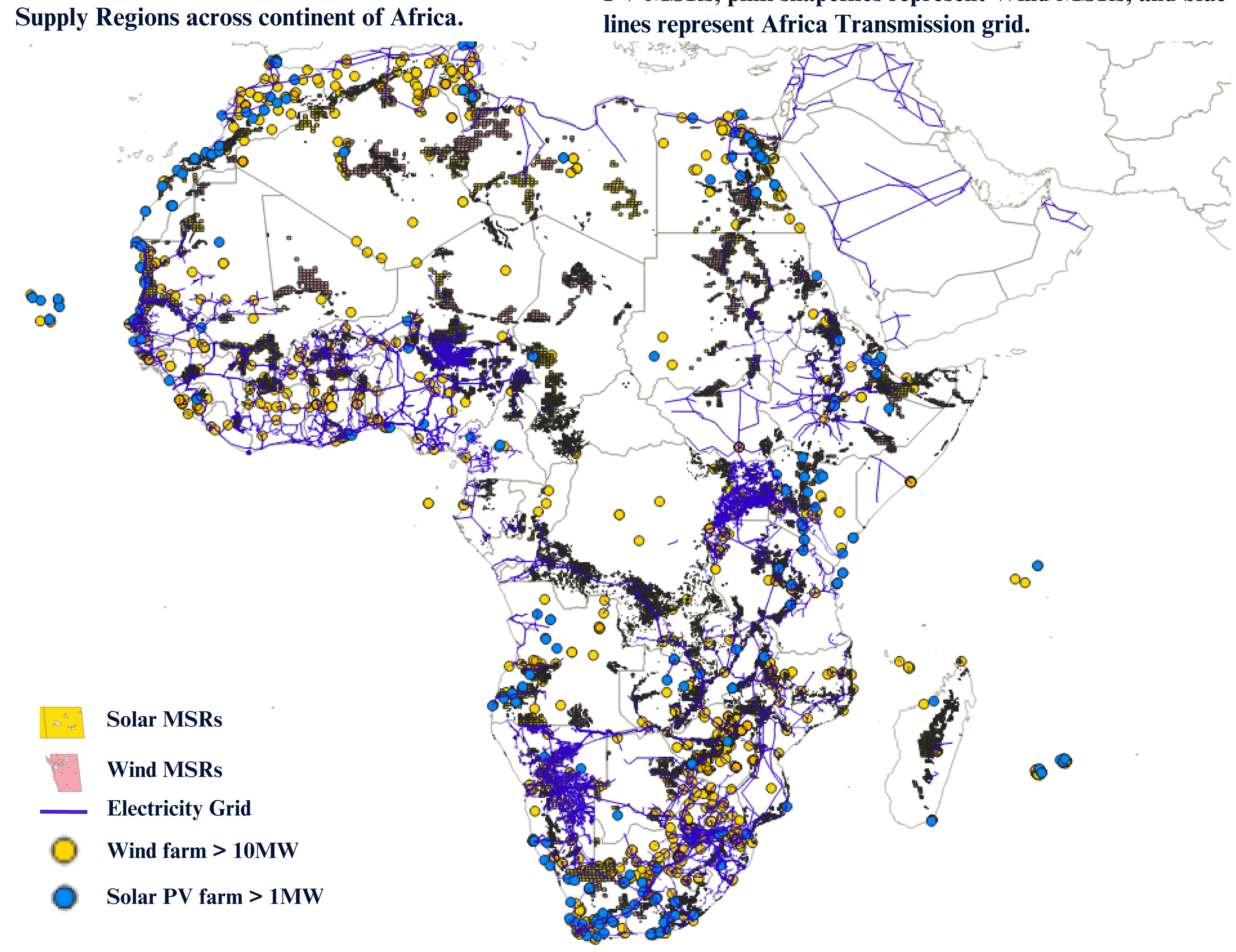


Fig 3. Visualization of solar PV and wind farms points with respective MSRs, and Africa transmission grid. Yellow points represent Solar PVs, blue points represent Wind farms.

Results and Conclusions

Solar Energy Validation

- A total of 542 operational and 591 planned utility-scale solar PV projects were analyzed across Africa. Approximately 30% of operational and 32% of planned plants fall inside MSRs (within a 10 km buffer).
- Inside-MSR sites represent 53% of operational installed capacity (6.7 GW), indicating that larger plants tend to coincide with model-identified optimal zones. Projects located inside MSRs show lower average LCOE (111 vs 117 USD/MWh), slightly higher capacity factors (19.7% vs 19.1%), and significantly closer proximity to the grid (14 km vs 47 km).

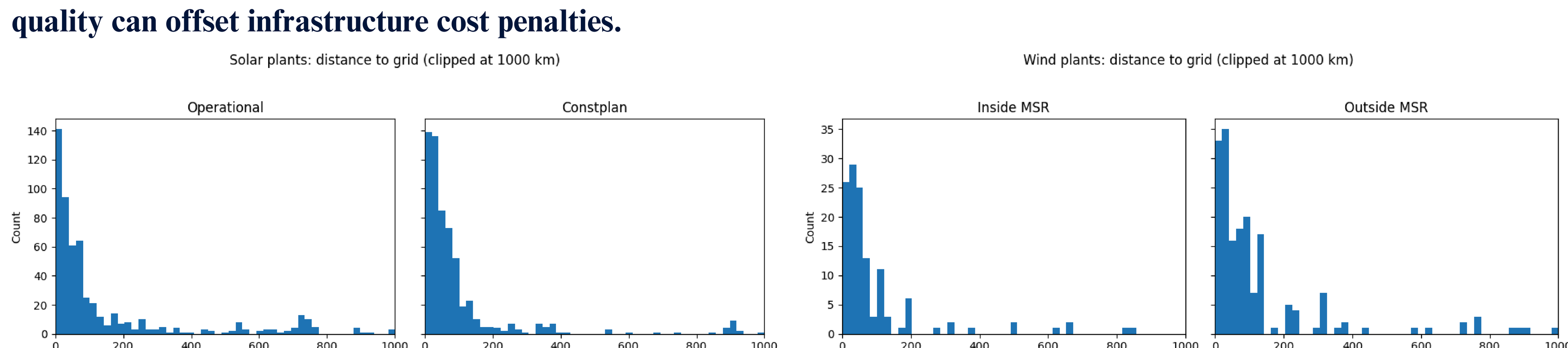
Satellite Validation (TZ-SAM, Independent satellite detections)

Dataset identified 889 PV clusters, of which 97 (11%) fall directly inside MSRs and 84% within 300 km proximity. TZ-SAM's satellite detections are independent of capacity threshold, thus detects low capacity Solar PVs.

Wind Energy Validation

- A total of 308 wind projects (operational and planned), about 42% of wind plants overlap with MSRs, showing better spatial alignment than solar PVs.
- Inside-MSR wind plants have an average distance to grid of 98 km versus 133 km for those outside, and higher average CF (46.5% vs 44.3%) with lower LCOE (64 vs 71 USD/MWh).

Unlike solar PV, wind developments show a greater tolerance for remoteness — supporting the hypothesis that wind quality can offset infrastructure cost penalties.



Transmission Grid Relationship

The median distance of solar plants to transmission lines is <20 km, while the median for wind is ~50 km. In contrast, the majority of high-CF, low-LCOE MSRs lie beyond 50 km, reinforcing that infrastructure expansion is the key to renewable deployment.

Stranded Solar Potential

Using the criteria LCOE < 110 USD/MWh, CF > 20%, and DistToGrid > 50 km, 298 "stranded" solar MSRs were identified, representing about 4% of the total screened area and an estimated 198.6 GW of high-quality potential. *Somalia, Angola, Ethiopia, Namibia, and South Africa,* have MSRs where resource quality is high but transmission infrastructure is sparse.

Conclusion

The study further illustrates the value of integrating nontraditional data sources, such as satellite-derived detection (TZ-SAM), for continuous model verification in data-scarce regions. Future research could expand upon temporal validation, incorporating commission dates to assess how MSR predictive accuracy evolves over time. As time passes, same analysis can be done again based on evolving grid and road datasets, to assess validation, and could reshape least-cost zones under new infrastructure. Further possible extension on this project could be integrating socio-environmental screening include social, ecological, and political risk layers to identify sites that are not only least-cost but also socially and environmentally viable.

Reference

- Sterl, S. et al. (2022). An all-Africa dataset of wind and solar energy model supply regions. Nature Scientific Data, 9, 715. https://www.nature.com/articles/s41597-022-01786-5
- World Bank (2020). Africa Electricity Transmission and Distribution Grid Map. https://datacatalog.worldbank.org/search/dataset/0040465/africa-electricity-transmission-and-distribution-grid-map
- Global Energy Monitor (2025). Africa Energy Tracker, May 2025 Release. Open dataset under CC license. Attribution required for reuse or adaptation. https://globalenergymonitor.org
- TransitionZero (2025). Solar Asset Mapper (TZ-SAM), Q1 2025 Data Release. https://www.transitionzero.org/insights/tz-sam-solar-asset-mapper-q1-2025-data-release

Acknowledgements

This research was supported by the DKU Summer Research Scholars (SRS) Program and Office of Academic Services.