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Technico-Economic Analysis of Solar Tracking (Tracker) and Fixed Photovoltaic Systems: Case Study in Conakry

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ABSTRACT

Background and Aim: The addition of solar tracking systems (trackers) allows for an increase in photovoltaic energy production under tropical climates, as demonstrated in Conakry. However, this performance increase comes with increased mechanical and electronic complexity.
Method: This article presents a comparative techno-economic analysis between a fixed system and a single-axis tracker system (60 Wp), integrating capital expenditures (CAPEX), operational and maintenance costs (OPEX), as well as the parasitic consumption of the tracking system.
Results: Experimental results show a gross production gain of 40.2%, which reduces to a net real gain of 31.2% once parasitic consumption is deducted. Economically, for a micro-generation application, the Levelized Cost of Energy (LCOE) in an off-grid site is 0.25 USD/kWh for the fixed system compared to 0.45 USD/kWh for the tracker, with a payback period for the latter exceeding 21 years. These results reveal that while the tracker is technically superior, it is only economically viable for installations with a capacity greater than one kilowatt-peak (kWp), due to the incompressible fixed cost of control electronics at a small scale.
Conclusion: The study concludes with a recommendation against using trackers for small solar lamps or domestic kits, but advocates for their deployment in rural mini-grids and industrial installations.

Keywords: Techno-economic analysis, LCOE, Solar tracker, Profitability, Photovoltaic energy, Guinea.

INTRODUCTION

Access to reliable and affordable electricity remains one of the most pressing development challenges in Sub-Saharan Africa, where nearly 600 million people still lack access to modern energy services [1].

In Guinea, despite abundant renewable energy resources, the national electrification rate remains below 45%, with rural areas disproportionately affected. The country's energy mix is still heavily dependent on imported fossil fuels and large-scale hydropower, both of which are vulnerable to price volatility and seasonal variability, respectively. In this context, the energy transition in Guinea relies heavily on exploiting the solar potential, estimated at 5 - 6 kWh/m²/day in Conakry, which positions the country among the most promising markets for photovoltaic (PV) deployment in West Africa [2].

While technical studies consistently prove that solar tracking systems (trackers) increase energy yield by 28% to 40% compared to fixed installations, the decision to implement these technologies depends not only on physics but also on their economic viability. Tracking systems optimize the angle of incidence between sunlight and the PV panel throughout the day, thereby maximizing energy capture during peak irradiance hours [3].

However, integrating a tracker requires actuators, sensors, a control unit, and often a dedicated battery, which significantly increases both the initial capital expenditure (CAPEX) and ongoing operational and maintenance costs (OPEX). This added complexity raises critical questions about the cost-effectiveness of tracking systems, particularly at small scales and in off-grid applications prevalent across rural Guinea [4].

Despite a growing body of literature on the techno-economic assessment of PV tracking systems few studies have specifically addressed the micro-generation segment (< 1 kWp) under tropical West African climatic conditions. This gap is significant, as the economics of tracking systems are highly scale-dependent, and conclusions drawn from utility-scale installations cannot be directly extrapolated to small domestic or community-level systems [5, 6].

The objective of this article is to bridge this gap by determining the break-even point and the Levelized Cost of Energy (LCOE) for both fixed and single-axis tracking systems experimentally tested at the Kofi Annan University of Guinea in Conakry. The findings aim to provide evidence-based recommendations to local investors, development agencies, and policy-makers regarding the appropriate scale and context for tracker deployment in Guinea's evolving energy landscape.

MATERIALS AND METHODS

Energy Production Data Based

Energy production data based on experiments conducted in Conakry (March-April), the average daily net energy productions are: (i) Fixed System (60 Wp): 56.0 Wh/day, (ii) Tracker System (60 Wp): 78.5 Wh/day, (iii) Gross gain: +40.2%

Economic Indicators to compare the two systems

Economic Indicators to compare the two systems, we use three standard indicators of energy financial engineering [7, 8]: (i) CAPEX (Capital Expenditures): Total cost of acquisition and installation, (ii) OPEX (Operational Expenditures): Maintenance, cleaning, component replacement (battery), and the cost of the energy consumed by the tracker (parasitic load) and (iv) LCOE (Levelized Cost of Energy): The discounted cost of energy over the system's lifetime, expressed in USD/kWh.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{CAPEX + OPEX_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where E_t is the energy produced in year t, n is the lifetime, and r is the discount rate, set at 8% for the local context).

Cost estimation in the guinean market context

Costs are estimated in US dollars (USD) based on the average prices of imported solar equipment available on the Conakry market for small off-grid installations.

Tableau 1. Capital Expenditures (CAPEX)

Component	Fixed System (USD)	Tracker System (USD)
Solar Panels (2 x 30Wp)	60	60
Support structure (Steel/Aluminum)	25	45 (Rotating structure)
DC Wiring and Protections	15	20
MPPT Charge Controller 15A	0 (Simple fixed)	35

Tracking system (Arduino, LDR, Stepper motor)	0	45
12V 8Ah Battery (Dedicated to tracking)	0	25
Labor and Installation	20	40
TOTAL CAPEX	**120 $**	**270 $**

The tracker system costs 2.25 times more than the fixed system for the same installed peak power.

Operational and Maintenance Costs (OPEX)

- Parasitic consumption of the tracker: The motor and Arduino board consume about 5 Wh/day. Over a year, this represents 1.82 kWh/year lost to run the system.
- Maintenance: The fixed system requires bi-monthly cleaning (negligible cost). The tracker requires mechanical checks, axis greasing, and replacement of the lead-acid battery every 4 years.
- Smoothed annual OPEX: Fixed = 2/yearand Tracker=12/yearand Tracker=12/year (including the pro-rata of battery replacement and mechanical maintenance).

RESULT AND DISCUSSIONS

Annual Net Energy Balance In Conakry, the annual production (over 365 days) is:

- Fixed: 56 Wh/day × 365 = 20.44 kWh/year
- Tracker: (78.5 Wh/day × 365) - 1.82 kWh (parasitic) = 26.83 kWh/year
- Net real gain: 6.39 kWh/year (31.2% of useful additional energy).

LCOE and Payback Period Calculation The price of electricity in Guinea varies depending on the context. We evaluate profitability according to two scenarios:

- Scenario A (Grid-connected to EDG): Average tariff 0.12 USD/kWh.
- Scenario B (Off-grid / Diesel generator replacement): Energy cost 0.40 USD/kWh.

Tableau 2. Economic comparison between Fixed and Tracker systems

Economic Indicator	**Fixed System**	**Tracker System**
CAPEX	120.00 $	270.00 $
Annual Energy (kWh)	20.44	26.83
LCOE (Grid Scenario - 20 years)	0.18 USD/kWh	0.31 USD/kWh
LCOE (Off-grid Scenario - 10 years)	0.25 USD/kWh	0.45 USD/kWh
Payback Period (Scenario B)	7.5 years	21.5 years

DISCUSSION

Interpretation of Results At the 60 Wp scale, the fixed system is economically much more profitable. The LCOE of the tracker is almost double that of the fixed system. The payback period of the tracker exceeds the lifespan of some of its electronic components (such as the 12V battery). The CAPEX overrun ($150 additional) is not compensated by the financial gain of the additional 6.39 kWh produced annually. The previous analysis seems unfavorable to the tracker. However, it highlights a crucial scale bias for engineers and investors [9, 10].

The micro-generation problem In our study, the control system (Arduino, LDR sensors, stepper motor) represents an incompressible fixed cost ($80). Whether the system is 60 Wp or 600 Wp, this base "brain" and "muscle" cost remains similar. It is this fixed cost that destroys profitability at a small scale.

Scale-Up to kWp If we extrapolate this study to a standard 3 kWp domestic installation (i.e., 100 panels of 30W): the cost of panels and linear structures increases, the cost of the control electronics (Arduino/Sensors) does not increase (a single microcontroller can drive a large mechanical axis) and the +31% energy gain applies to a 3000 Wp base, generating a massive gain of 315 kWh/year. Recent studies in West Africa demonstrate that for installations greater than 1 kWp in off-grid sites, the LCOE of single-axis trackers becomes 15% to 20% lower than that of fixed systems, because the energy gain largely compensates for the amortization of the motorized structure [11, 12, 13, 17].

CONCLUSION

The techno-economic analysis of photovoltaic systems tested in Conakry reveals a critical duality between physical performance and financial viability. Technically, the tracking system significantly outperforms the fixed-tilt configuration with a net production gain of 31.2% after accounting for parasitic consumption. However, this technical superiority does not translate into economic advantage at all scales. For micro-generation applications (60 Wp), the fixed system remains financially optimal with an LCOE of 0.25 USD/kWh compared to 0.45 USD/kWh for the tracker, an 80% premium driven primarily by the capital expenditure of control electronics and associated maintenance costs.

Consequently, strategic implementation guidelines for the Guinean solar sector must be clearly differentiated by scale. The deployment of solar trackers should be discouraged for small-scale decentralized applications such as solar lamps and domestic kits, where simplicity, low upfront costs, and minimal maintenance are paramount. Conversely, tracking technology is highly recommended for rural mini-grids and industrial installations exceeding 3 kWp. At these larger scales, the higher initial cost of tracking electronics is effectively diluted across greater energy output, maximizing return on investment and significantly reducing the overall LCOE.

Ultimately, aligning PV technology choices with the specific scale and economic context of end-users is essential for Guinea's energy transition. Policymakers and investors should prioritize fixed systems for immediate rural off-grid lighting while reserving tracking technologies for productive use and mini-grid projects to ensure efficient resource allocation. As the global cost of photovoltaic components and electronic controllers continues to decline, this strategic differentiation will ensure the long-term sustainability and economic viability of Guinea's expanding solar infrastructure.

Declaration by Authors

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