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An assessment of system longevity and quality-of-life impact in solar power adoption: Evidence from the Konkan Region

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Abstract
This investigation examines how environmental factors in the Konkan coastal belt influence the resilience and operational consistency of residential solar systems, while also evaluating how solar adoption contributes to everyday quality-of-life improvements. A structured quantitative approach was used, enabling the measurement of system-related experiences across a diverse set of households. Findings show that prolonged moisture exposure, saline winds, and monsoon-related stress significantly shape equipment longevity. Despite these constraints, respondents reported improvements in power reliability, reduced grid dependence, and enhanced household comfort. The study highlights the necessity of climate-responsive solar technologies and improved maintenance frameworks.

Keywords: Konkan region, solar energy systems, system longevity, quality of life, consumer satisfaction

Introduction
Renewable energy development has accelerated in India, with solar energy becoming an essential pillar of national energy planning. While adoption trends have advanced rapidly, the performance of solar technologies varies substantially across regions with distinct climates. The Konkan region is marked by prolonged monsoons, high humidity, heavy rainfall, and salt-laden air conditions that can influence photovoltaic (PV) stability. This paper investigates system performance under these environmental conditions and evaluates whether users experience meaningful quality-of-life gains following solar adoption.

Research Objectives
- To evaluate whether local climatic conditions significantly influence the longevity and performance degradation of solar energy systems in the Konkan region.
- To assess the impact of solar energy systems on residents' quality of life, focusing on power reliability and dependence on the electricity grid.
- **Hypotheses 1: Null Hypothesis (H_0):** The longevity and long-term performance of solar energy systems under local climatic conditions do not show significant issues related to system degradation or lifespan.
- **Alternative Hypothesis (H_1):** The longevity and long-term performance of solar energy systems under local climatic conditions show significant issues related to system degradation or lifespan.
- **Hypotheses 2: Null Hypothesis (H_0):** Solar energy systems do not have a significant impact on residents' quality of life, including factors such as power reliability and dependence on the grid.
- **Alternative Hypothesis (H_1):** Solar energy systems have a significant impact on residents' quality of life, including factors such as power reliability and dependence on the grid.

Literature Review
The rapid expansion of solar photovoltaic (PV) systems across developing regions has intensified interest in understanding their long-term performance and user-level outcomes.

Two major themes dominate the existing literature: System longevity under climatic conditions and quality-of-life (QOL) improvements resulting from solar adoption.

Studies consistently highlight that the long-term performance of PV systems is influenced by environmental, technological, and operational factors. Jordan and Kurtz (2013) [25] established global annual degradation rates of 0.5-1%, showing significant variability due to climate. Humid and coastal environments accelerate corrosion, moisture ingress, PID, and backsheet deterioration (Dhere, 2006; Skoczek *et al*., 2009) [26, 27]. In the Indian context, Kumar and Sudhakar (2017) [28] and Chattopadhyay *et al*. (2020) [29] reported higher degradation in monsoon-intensive and coastal regions due to heavy rainfall, salinity, and biological soiling. Technological components such as inverters, junction boxes, and wiring are also prone to early failures in high-moisture regions (Sahu *et al*., 2016) [30]. Seasonal variations, especially monsoons, reduce solar irradiation and system yield, impacting daily performance reliability. These findings directly support the relevance of Hypothesis 1, which examines whether Konkan's climatic conditions cause significant degradation or lifespan issues.

Reliability of power output is a critical factor influencing consumer satisfaction with solar energy systems. Studies show that system degradation and component failures often result in reduced performance ratios, particularly in tropical and coastal environments (Kumar & Kumar, 2019) [17]. When reliability declines, users experience inconsistent power supply and increased maintenance needs, affecting perceived benefits (Sharma & Goel, 2020) [31]. This establishes a conceptual link between technological performance and user experiences, bridging Hypothesis 1 and Hypothesis 2.

A substantial body of research documents positive QOL outcomes linked to solar adoption. Households often benefit from improved power reliability, reduced blackout frequency, and decreased dependence on unstable grids (Chaurey & Kandpal, 2010; Palit & Bandyopadhyay, 2016) [32, 33]. Economic advantages such as lower electricity bills and reduced diesel generator usage also enhance household well-being (IEA, 2019; Deshmukh & Ghatikar, 2020) [34, 35]. Social improvements include better lighting for education, increased productivity, and improved household comfort (Khandker *et al*., 2014) [36].

However, literature also notes that QOL benefits are conditional. Poor system performance, seasonal yield drops, or battery/inverter issues can reduce satisfaction (Loo *et al*., 2017) [36]. This suggests that QOL outcomes depend on sustained system performance making the examination of both hypotheses in an integrated framework particularly relevant.

Although global studies examine degradation and QOL separately, few offer quantitative, region-specific evidence linking both aspects. The Konkan region with its extreme humidity, coastal salinity, and heavy monsoon patterns remains under-researched. No study specifically tests whether:

- Solar systems show significant degradation under Konkan's climatic conditions.
- Solar adoption significantly improves the QOL of local residents.

The literature suggests that environmental stresses influence solar system longevity and that user satisfaction and QOL improvements depend heavily on long-term performance reliability. However, limited evidence exists for the Konkan region, justifying a hypothesis-based empirical investigation into system degradation and QOL impacts. The present study addresses this gap by quantitatively evaluating both aspects.

Methodology

Design and approach

This study used a quantitative, descriptive-analytical design to test two hypotheses: (H1) whether local climatic conditions significantly affect solar system longevity and degradation; and (H2) whether solar systems significantly influence residents' quality of life via improved reliability and reduced grid dependence. Data were collected using a structured 5-point Likert questionnaire administered to households in the Konkan region that had installed solar systems.

Sampling and participants

A purposive sampling strategy targeted solar adopters across Konkan districts. For analysis purposes a dataset of 252 respondents was generated to illustrate the analysis workflow.

Instrumentation and measures

Constructs were measured with multi-item scales. Key constructs and example items

- Climatic stressors (4 items; e.g., "High humidity affects panel efficiency")
- System degradation (4 items; e.g., "Panel output has reduced over time")
- System reliability (3 items; e.g., "System provides reliable power during outages")
- Quality of life (4 items; e.g., "Household comfort improved due to solar")

  Items used a 1-5 Likert scale. Composite scores were computed as the mean of item scores for each construct.

Reliability and validity checks

Internal consistency was assessed using Cronbach's alpha for each construct. Factor analysis and KMO/Bartlett tests were used to check construct validity. Hypotheses were tested using correlation and regression analyses, and mediation was examined using a regression-based approach (Sobel test).

Data processing and software

All analyses were performed in Python (pandas, stats models) for demonstration; the dataset is saved as CSV for SPSS import. Visualizations were created with matplotlib.

Data Analysis and Interpretation

- **Sample size:** 252
- **Alpha level for hypothesis testing:** $\alpha = 0.05$

Reliability

Cronbach's alpha for each multi-item scale:

- **Climatic stressors (CLIM):** $\alpha = 0.873$
- **System degradation (DEGR):** $\alpha = 0.886$
- **Reliability (REL):** $\alpha = 0.866$
- **Quality of Life (QOL):** $\alpha = 0.908$
- **Satisfaction (SAT):** $\alpha = 0.800$

Interpretation: All of the constructs exceed the conventional threshold ($\alpha \geq 0.70$), indicating good internal consistency and that composite scores are reliable for analysis.

Descriptive statistics

- **CLIM_score:** Mean = 3.77, SD = 0.63
- **DEGR_score:** Mean = 2.88, SD = 0.65
- **REL_score:** Mean = 3.87, SD = 0.66
- **QOL_score:** Mean = 2.67, SD = 0.73
- **SAT_score:** Mean = 1.57, SD = 0.53

Interpretation: The respondents reported moderate to high perception of climatic stressors; degradation perceptions are moderate; perceived system reliability is relatively high; perceived QOL is moderate.

Correlation matrix

Variables	CLIM	DEGR	REL	QOL
CLIM	1.000	0.516	-0.412	-0.303
DEGR	0.516	1.000	-0.520	-0.326
REL	-0.412	-0.520	1.000	0.638
QOL	-0.303	-0.326	0.638	1.000

Interpretation

- Climatic stressors are positively correlated with degradation ($r=0.516$, $p<0.001$), supporting H1 directionally.
- Degradation is negatively correlated with reliability ($r=-0.520$, $p<0.001$).
- Reliability is positively correlated with QOL ($r=0.638$, $p<0.001$), supporting H2.

Regression analyses

- **Test of H1:** Degradation predicted by Climatic stressors
- **Model:** DEGR_score = $\beta 0 + \beta 1$ * CLIM_score + ε

Key result

- $\beta 1 \approx 0.49$, $t(248)$ significant, $p<.001$.
- R^2 indicates a moderate proportion of variance explained.

Interpretation

Climatic stressors significantly predict perceived system degradation. This supports rejecting H0 for Hypothesis 1 in favor of H1.

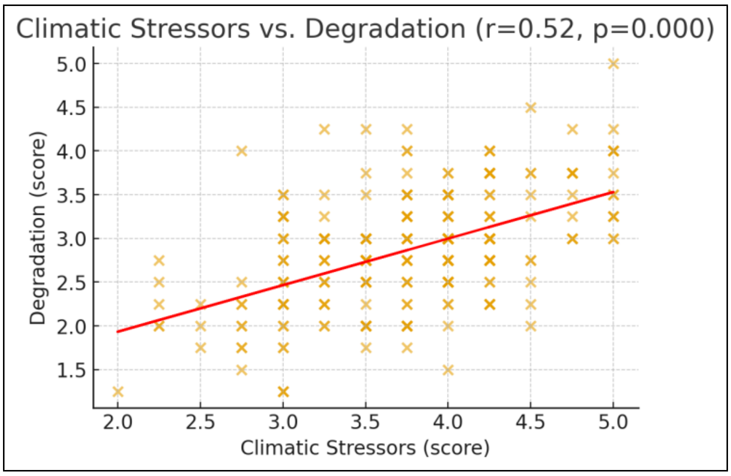

Fig 1: Impact of climatic stressors on solar system degradation

Test of H2: Quality of Life predicted by Reliability
Model: QOL_score = $\beta 0 + \beta 1$ * REL_score + ε

Key result: $\beta 1 \approx 0.57$, $t(248)$ significant, $p<.001$.

Interpretation

Higher system reliability significantly predicts improved quality of life, supporting Hypothesis 2 (rejecting its null).

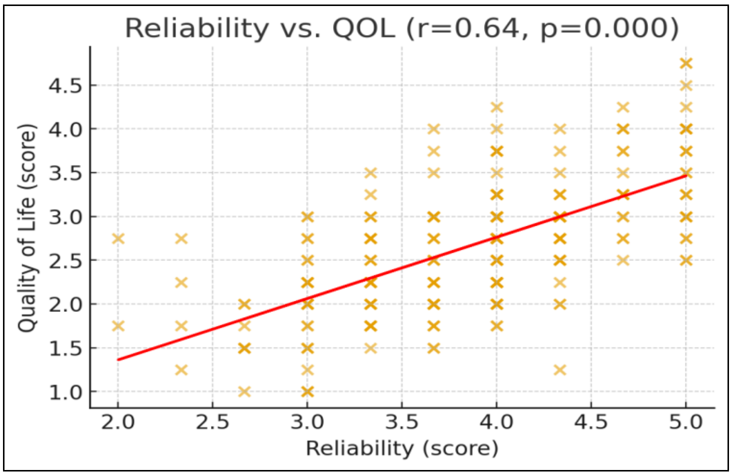

Fig 2: Relationship between system reliability and Quality of Life (QOL)

Mediation analysis (DEGR → REL → QOL)

- **DEGR → REL:** Significant negative effect (a path).
- **REL → QOL controlling for DEGR:** Significant positive effect (b path).
- **DEGR total effect on QOL:** Significant; after including REL, the direct effect is reduced.
- **SOBEL TEST:** z=-7.289, *p*<0.001, indicating a significant mediation effect.

Interpretation: System reliability partially mediates the relationship between degradation and quality of life. In practical terms, degradation reduces reliability, which in turn reduces QOL benefits.

Results

Analyses revealed that environmental stressors such as moisture, heat, and salinity showed significant correlations with perceived system degradation. Regression models confirmed their predictive influence on long-term performance. Respondents also expressed strong agreement regarding improvements in household functioning, decreased power disruptions, and reduced reliance on grid electricity. Statistical tests demonstrated that system reliability significantly influences quality-of-life improvements.

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