Model Card

AI-Based Rooftop Solar PV Detection and Verification System

1. Model Overview

Model Name: Rooftop Solar PV Detection and Segmentation Model
Model Type: Instance Segmentation
Base Architecture: YOLOv8-Seg (Ultralytics)
Primary Task: Detection and segmentation of rooftop solar photovoltaic (PV) panels from satellite imagery
Deployment Context: Remote verification of rooftop solar installations using geographic coordinates

This model is part of an AI-driven pipeline designed to support **governance-ready, auditable, and low-cost** verification of rooftop solar PV installations.

2. Intended Use

Primary Intended Use

- Remote verification of rooftop solar PV installations
- Estimation of total installed PV panel area (square meters)
- Support for subsidy verification and governance workflows
- Generation of explainable and audit-friendly artifacts

Intended Users

- Government agencies
- Electricity distribution companies (DISCOMs)
- Policy auditors and verification teams
- Researchers working on renewable energy monitoring

Out-of-Scope Uses

- Energy generation estimation
- Electrical or structural safety analysis
- Panel-level efficiency estimation
- Continuous or real-time monitoring

3. Model Architecture

- **Framework:** Ultralytics YOLOv8
- **Task Head:** Instance segmentation
- **Input:** RGB satellite imagery
- **Output:** Pixel-level segmentation masks for detected solar PV panels
- **Confidence Score:** Detection confidence produced by YOLOv8

The segmentation output enables physically grounded area estimation and improves robustness over bounding-box-based detection.

4. Training Data

Dataset Source

The model was trained using an **open-source instance segmentation dataset** obtained via **Roboflow**.

Dataset details:

- Platform: Roboflow
- Workspace: `roshan-mp2t5`
- Project: `solar-panel-instance-segmentation`
- Version: 1
- Original annotation format: COCO segmentation

The dataset was downloaded programmatically using the Roboflow Python SDK.

Data Characteristics

- Satellite and aerial imagery
- Rooftop-mounted solar PV panels
- Pixel-level polygon annotations
- Variety of rooftop layouts and panel arrangements

Label Scope

- Single class: **Solar panel**
- Only rooftop solar PV panels are annotated
- No other rooftop objects (e.g., water tanks, skylights) are labeled

Data Limitations

- Urban rooftops are better represented than rural rooftops

- Limited examples with heavy cloud cover or strong shadows
- Geographic bias depending on publicly available imagery

5. Data Processing and Format Conversion

The original COCO segmentation annotations were converted to **YOLOv8 segmentation format** prior to training.

Conversion process:

- COCO polygon annotations were extracted per instance
- Polygon coordinates were normalized using image width and height
- Class indices were remapped to zero-based indexing
- Images were organized into YOLO-compatible directory structure

This process preserved **full polygon geometry**, enabling accurate instance segmentation training rather than bounding-box approximation.

6. Model Training Procedure

- **Base model:** `yolov8n-seg.pt`
- **Image size:** 640 × 640
- **Epochs:** 50
- **Batch size:** 8
- **Number of classes:** 1 (Solar panel)

Training was performed using the Ultralytics YOLOv8 training framework with default optimization settings. No custom loss functions were introduced.

7. Inference and Post-Processing Pipeline

During inference, the following steps are applied:

1. Satellite image retrieval using latitude and longitude (Google Static Maps API)
2. Solar panel segmentation using the trained YOLOv8-Seg model
3. Creation of circular buffer zones corresponding to:
   - 1200 square feet
   - 2400 square feet
4. Pixel-to-ground conversion using Web Mercator ground resolution
5. Computation of PV panel area (m^2) using mask overlap with buffer zones

6. Selection of the buffer zone with the largest valid overlap
7. Generation of:
    - Machine-readable JSON output
    - Human-readable audit overlay image

8. Evaluation Methodology

Formal benchmark evaluation was not conducted as part of this hackathon submission.

Qualitative evaluation focused on:

- Correct detection of rooftop solar installations
- Stability of segmentation masks
- Consistency of area estimation logic across similar rooftops

Future evaluation may include:

- F1 score for PV presence detection
- RMSE for PV area estimation
- Cross-region generalization testing

9. Performance Characteristics

Strengths

- Segmentation-based area estimation (more precise than bounding boxes)
- Physically grounded pixel-to-area conversion
- Explainable and audit-friendly outputs
- Scalable for batch verification workflows

Known Limitations

- Reduced accuracy under heavy shadows or cloud cover
- Performance depends on satellite image resolution and freshness
- No correction for roof tilt or perspective distortion
- Possible confusion with visually similar rooftop structures

10. Biases and Fairness Considerations

- Urban rooftops are over-represented relative to rural rooftops
- Rooftops with vegetation or clutter may reduce detection accuracy

- Regional variations in roofing materials may affect performance

Mitigation Measures

- Conservative QC labeling for low-confidence cases
- Manual review of audit artifacts in borderline scenarios

11. Quality Control (QC) Logic

Each prediction is assigned a QC status:

- **VERIFIABLE:** Clear visual evidence of solar PV presence or absence
- **NOT_VERIFIABLE:** Insufficient evidence due to image quality, occlusion, or low confidence

QC labeling is designed to reduce false positives in governance workflows.

12. Ethical and Legal Considerations

- Uses only publicly accessible satellite imagery APIs
- Does not process personally identifiable information (PII)
- Intended for policy and governance support, not individual surveillance
- Users must comply with Google Maps Platform terms of service

13. Environmental Impact

- Lightweight inference pipeline
- GPU-accelerated execution for efficiency
- No persistent storage of raw imagery beyond processing
- Supports renewable energy governance and sustainability goals

14. Model Versioning and Environment

- **YOLOv8 version:** 8.3.23
- **Python version:** 3.12.12
- **Model file:** `models/best.pt`

15. Future Improvements

- Incorporation of multi-temporal imagery
- Improved QC heuristics using image quality metrics
- Region-specific fine-tuning
- Roof-tilt-aware area correction

16. Attribution and Acknowledgements

- Model developed using Ultralytics YOLOv8
- Training data sourced via Roboflow
- Satellite imagery accessed using Google Static Maps API