Solar Panel Detection System - Model Card

EcoInnovators Ideathon 2026

Model Overview

Model Name: Solar Panel Rooftop Detection Ensemble

Model Type: 3-Model YOLOv8s-seg Ensemble

Task: Object Detection + Instance Segmentation

Version: 1.0

Date: December 2025

Architecture:
- Primary Model: YOLOv8s-seg (22.76 MB)
- Ensemble Model v2: YOLOv8s-seg (22.52 MB)
- Ensemble Model v3: YOLOv8s-seg (23.86 MB)
- Total Size: 69 MB combined

Performance:
- Primary Model mAP@0.5: 94.3%
- Ensemble Strategy: Equal weighting (33.3% each)
- Inference Time: 3-4 seconds per location
- Confidence Threshold: 0.25-0.30

Training Data

Dataset Composition

The ensemble was trained on multiple comprehensive datasets totaling ~32,876 images:

Primary Model (6,876 images):

1. Custom Workflow Dataset: 4,739 images

2. LSGI547 Dataset: 389 images

3. Solarpanel_seg v4: 528 images

4. Zeewolde Solar Farm: 210 images

5. Solar panels v1i: 367 images

6. Solarpv-INDIA: 293 images

Ensemble Model v2:

- Custom workflow variations

- Training focus: Detection robustness

Ensemble Model v3 (Largest Dataset):

- ~26,000 images from diverse sources

- Training focus: Coverage and generalization

Data Characteristics

Image Types:

- Satellite imagery (primary)

- Aerial drone photography

- Ground-level installations

- Multi-resolution sources (0.05m to 0.5m per pixel)

Geographic Coverage:

- India (primary focus)

- Europe (Zeewolde, Netherlands)

- Mixed global locations

Annotations:

- Instance segmentation masks (polygon format)

- COCO format annotations

- Class: "solar-panel" (single class detection)

Data Split:

- Training: ~92% of data

- Validation: ~8% of data

- Test: Real-world inference on PM Surya Ghar locations

Model Training

Training Configuration

Framework: Ultralytics YOLOv8

Input Size: 640×640 pixels

Batch Size: 16 (primary), 8 (ensemble models)

Epochs: 50-100 epochs per model

Optimizer: SGD with momentum

Hyperparameters:

- Learning Rate: 0.01 (initial)

- Momentum: 0.937

- Weight Decay: 0.0005

- IoU Threshold: 0.45

- Confidence Threshold: 0.25

Augmentation:

- Random flips, rotations

- Mosaic augmentation

- Color jitter and brightness adjustments

- Scale variations (0.5x to 1.5x)

Training Environment

Hardware:

- Primary: Consumer laptop with GPU

- Ensemble models: Mixed training environments

- Total Training Time: ~120+ hours combined

Software:

- PyTorch 2.0+

- CUDA 11.8+

- Ultralytics YOLOv8 framework

Model Capabilities & Limitations

Capabilities

 High Accuracy: 94.3% mAP on validation set

 Dual Output: Bounding boxes + segmentation masks

 Fast Inference: 30-40ms per image (ensemble)

 Robust Detection: Handles various angles, sizes, and lighting

Buffer Zone Filtering: Supports 1200/2400 sq ft spatial analysis

Known Limitations

Image Quality Dependencies:

- Performance degrades with heavy cloud cover

- Low-resolution imagery (<0.1m/pixel) reduces accuracy

- Shadows and occlusions can cause false negatives

- Water reflections may cause false positives

Geographic Bias:

- Primarily trained on Indian solar installations

- May require fine-tuning for other regions with different:

- Roof types and materials

- Panel mounting styles

- Climate/vegetation patterns

Detection Constraints:

- Small panels (<5 sq meters) may be missed

- Overlapping or densely packed panels may merge

- Unusual panel colors (non-blue) may reduce confidence

- Ground-mounted installations not in training scope

Scale Limitations:

- Optimal imagery resolution: 0.05-0.2m per pixel

- Very high zoom may fragment large installations

- Very low zoom may miss small panels

Failure Modes

Common Failure Scenarios

1. *False Negatives (Missed Detections):*
 - Panels covered by trees or shadows
 - Very small or fragmented installations
 - Poor image quality or cloud cover
 - Non-standard panel colors (white, green)

2. *False Positives (Incorrect Detections):*
 - Swimming pools (blue rectangular surfaces)
 - Blue tarpaulins or awnings
 - Glass skylights with reflections
 - Parking lot markings

3. *Segmentation Errors:*
 - Irregular polygon boundaries on angled roofs
 - Merged masks for closely spaced panels
 - Incomplete masks for partially occluded panels

Mitigation Strategies

- *Confidence thresholding:* Adjust 0.25-0.40 based on use case
- *Post-processing:* Apply area filters (min 5 sq meters)
- *QC status:* Flag "NOT_VERIFIABLE" for poor imagery
- *Manual review:* High-value applications require human verification

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Bias & Ethical Considerations

Dataset Bias

Geographic Bias:

- Training data skewed toward Indian installations

- May under-represent other architectural styles

Temporal Bias:

- Training imagery from 2020-2024 period

- May not capture latest panel technologies

Socioeconomic Bias:

- Mix of residential, commercial, and industrial

- Limited representation of rural/off-grid installations

Ethical Use

Intended Use:

- Verification for PM Surya Ghar subsidy scheme

- Preliminary screening for solar potential assessment

- Urban planning and energy policy analysis

Not Recommended For:

- Real-time surveillance or privacy invasion

- Sole decision-making without human review

- Property valuation or taxation (without verification)

- Legal disputes (must be verified by qualified inspector)

Quality Control

Model Validation

Metrics Tracked:

- mAP@0.5: 94.3% (primary model)

- Precision: ~92%

- Recall: ~89%

- F1-Score: ~90%

Quality Assurance:

- QC status determination (VERIFIABLE/NOT_VERIFIABLE)

- Image quality checks (brightness, contrast, resolution)

- Buffer zone validation (1200/2400 sq ft)

- Confidence scoring for all predictions

Retraining Guidance

When to Retrain:

- Model performance drops below 85% mAP

- Significant false positive/negative rates in production

- Expanding to new geographic regions

- New panel types not in training data

Retraining Process:

1. Collect 500+ new labeled samples from failure cases

2. Merge with existing training data

3. Retrain for 50 epochs with same hyperparameters

4. Validate on held-out test set

5. Compare performance metrics before deployment

Continuous Improvement:

- Log all predictions and confidence scores

- Sample low-confidence predictions for manual review

- Collect ground truth for challenging cases

- Quarterly model updates recommended

Model Outputs

Prediction Format

JSON Output:

json

```json
{
"sample_id": 1234,
"lat": 12.9716,
"lon": 77.5946,
"has_solar": true,
"confidence": 0.92,
"pv_area_sqm_est": 23.5,
"buffer_radius_sqft": 1200,
"qc_status": "VERIFIABLE",
"bbox_or_mask": "[[x1,y1],[x2,y2],...]",
"image_metadata": {
  "source": "ArcGIS World_Imagery",
  "resolution_m_per_pixel": 0.054,
  "fetch_area_sqft": 12900
}
}
```

Visual Outputs

- *Overlay Images:* Annotated satellite imagery with:
- GREEN boxes: Panels within buffer zone
- RED boxes: Panels outside buffer zone
- ORANGE circle: 1200 sq ft primary buffer
- GRAY circle: 2400 sq ft fallback buffer

Deployment Considerations

System Requirements

- Python 3.10+
- 4GB RAM minimum (8GB recommended)
- CUDA GPU optional (10x speedup)
- Stable internet for satellite imagery

Integration Points

REST API:
- POST /predict (single location)
- POST /predict/batch (multiple locations)
- GET /health (system status)

Batch Processing:
- Excel input support
- JSON output per sample
- Summary statistics report

References & Acknowledgments

Frameworks:

- Ultralytics YOLOv8: https://github.com/ultralytics/ultralytics

- PyTorch: https://pytorch.org

Datasets:

- Multiple open-source solar panel datasets

- Custom annotations for Indian installations

Challenge:

- EcoInnovators Ideathon 2026

- PM Surya Ghar Rooftop PV Verification

Contact & Maintenance

Model Version: 1.0

Last Updated: December 2025

Maintenance Schedule: Quarterly reviews recommended

For issues or questions regarding model performance, please refer to the README.md and technical documentation.

Document Version: 1.0

Date: December 14, 2025