

## Model Card - Solar Panel Detection System

### Model Details

- Developer:** Team: **Dude Coders**, Indian Institute of Technology Madras.
- Model:** YOLOv12x (Fine-tuned on Satellite Imagery).
- Approach:** Enhanced with Hard Negative Mining.
- Architecture:** YOLOv12x.
- Input:**  $1024 \times 1024$  px Satellite Tiles (Zoom 20).
- License:** MIT License (OSI-Approved).

### Intended Use

- Primary Use:** Automated verification of rooftop solar PV installations from high-resolution satellite imagery. Designed for the **EcoInnovators Ideathon 2026** challenge.
- Target Users:** Energy auditors, utility operators, urban planners.

### Model Logic & Assumptions

- Multi-Stage Fallback:** To address small/low-contrast panels, the system employs a 6-stage fallback strategy:
  - Initial full-image inference.
  - Spatial check within 1200/2400 sqft residential buffers.
  - Saturation enhancement (HSV +50%) if initial check fails.
  - Physical image cropping to buffer regions (Zoom-in).
- Assumptions:** Assumes panels are rectangular, dark/blue-tinted, and located on rooftop structures. Assumes clear weather conditions.

### Training Data

- Size:** 2,649 labeled images (80/20 train/val split).
- Composition:** Aggregated from **permissible open-source with full attribution**: Roboflow datasets (Alfred Weber Inst., LSGI547 Project, Piscinas Y Tenistable) [1, 2, 3] and custom collected samples from Google Maps Static API.
- Compliance:** No private or illegally obtained imagery was used in the training or testing of this model.
- Augmentation:** Heavy use of Mosaic, Mixup, HSV Color Jitter, and geometric transforms to simulate diverse lighting and angles.
- Hard Negative Mining:** Model specifically retrained on "negative" samples (roofs without solar) identified as False Positives to reduce confusion with shiny metal roofs.

### Limitations & Failure Modes

- Resolution Dependent:** Performance drops significantly below Zoom 20. Small panels ( $<1 m^2$ ) may be missed.
- Occlusion:** Heavy cloud cover, tree overhangs, or skyscraper shadows prevent detection.
- Look-alikes:** Blue water tanks, skylights, and dark waterproofing patches are common False Positives.
- Geographic Bias:** Trained on urban residential architectures.
- Area Approximation:** Surface area calculations are based on 2D bounding box projections; actual PV surface area may vary depending on the roof pitch and tilt angle relative to the satellite view.

### Retraining & Maintenance

- Monitor:** Track Flagged False Positives/Negatives.
- Update Process:**
  - Add misclassified samples to `EI_train_data.xlsx`.
  - Run `python train.py` to regenerate the dataset with hard negatives and retrain.
  - Replace `best.pt` with new weights.

### Ethical Considerations

- Privacy:** Analyzes public aerial imagery. No PII is processed.
- Bias:** Performance may vary by neighborhood wealth levels due to architectural differences (e.g., roof materials).

### Quantitative Analyses

#### Classification Performance

Class	Precision	Recall	F1	Support
No Solar	0.74	0.85	0.79	500
Solar	<b>0.97</b>	<b>0.94</b>	<b>0.95</b>	2500

#### Confusion Matrix

	Pred: No	Pred: Solar
Act: No	427 (TN)	73 (FP)
Act: Solar	153 (FN)	2347 (TP)

#### Performance Visuals

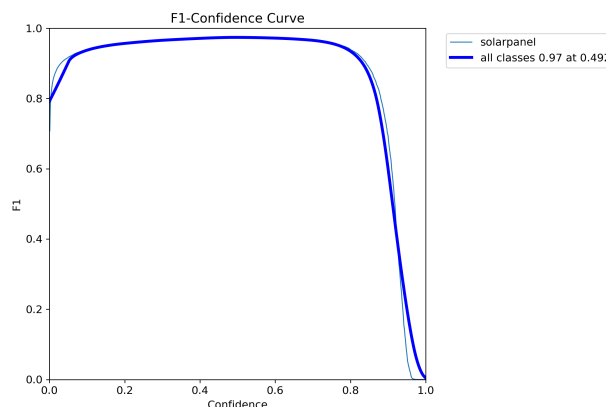


Figure 1: F1-Confidence Curve

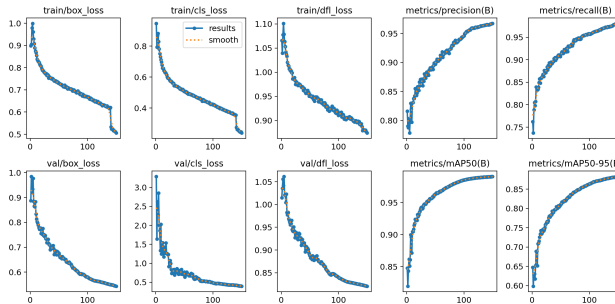


Figure 2: Training Plots

### Methodology: PV Area

The PV surface area is estimated through a three-step geometric process:

#### Step 1: Calculate Meters Per Pixel (MPP)

Based on the Mercator projection at latitude  $\phi$  and zoom level  $z$ :

$$MPP = \frac{156543.03392 \times \cos(\phi)}{2^z}$$

#### Step 2: Determine Pixel Area

For a detected bounding box with coordinates  $(x_1, y_1, x_2, y_2)$ :

$$Area_{px} = (x_2 - x_1) \times (y_2 - y_1)$$

#### Step 3: Compute Physical Area

The final area in square meters is the product of pixel area and the squared spatial resolution:

$$A_{m^2} = Area_{px} \times (MPP)^2$$

### References

- [1] Alfred Weber Inst. *Custom Workflow Dataset*. Roboflow Univ.
- [2] ProjectSolarPanel. *lsgi547-project*. Roboflow Univ.
- [3] Piscinas Y Tenistable. *Solar Panels*. Roboflow Univ.