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Energy Harvesting Evaluation of Photovoltaic Noise Barriers on Highways

Laura M. Soares and Dr. Hao Wang

NJDOT Research Showcase
Category: Energy/Electrification

Rutgers, The State University of New Jersey
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Background

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- U.S. Energy Department analysis shows that **solar energy** can scale up from **3% to 45%** of nation's electricity
- The **president has called for 100%** of the nation's electricity to come from **carbon pollution free source by 2035**
- Solar energy can provide **40% of the nation's electricity by 2035** according to Secretary of Energy Jennifer Granholm
- The goal of net zero emissions in the electricity sector by 2035 would require an **area bigger than the Netherlands** for the **solar industry** alone, according to research firm Rystad Energy.

Background

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- PVNB combine solar energy technologies with noise barrier structures - multiple uses of the same road and consumes a **limited amount of land**
- **Densely populated** areas usually require noise barriers close to residential neighborhoods - **less space available** for ground mounted PV (solar farms).

Fig 1: Visualization of proposed PVNB on existing noise barrier in Massachusetts from Massachusetts DOT

Fig 2: PVNB in Neuotting, Germany from Kohlhauer company

Objective and Scope

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- Evaluate the **potential energy** outputs of PVNB for retrofitting projects in **New Jersey**:
  - **PVNB configuration** selection: energy performance is analyzed varying **location, orientation** and barrier **configurations**
    - top-mounted tilted, top-mounted bifacial, vertical built-on, and shingles built-on.
  - Two specific noise barriers in New Jersey is selected to compare **energy outputs** of different **design configurations**
  - The **energy harvesting potential** of PVNB in the highway network of **New Jersey** is estimated

Methodology

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- Configuration performance analysis:
  - Locations were selected differing latitude, longitude and GHI.
  - Four PVNB configurations were simulated, and the energy output analyzed
- Case study with two NJ noise barriers – barriers with different orientations.
- State-level estimation: simulations were performed to elaborate a polynomial equation that describes the energy performance.

PVNB Design Configuration (1)

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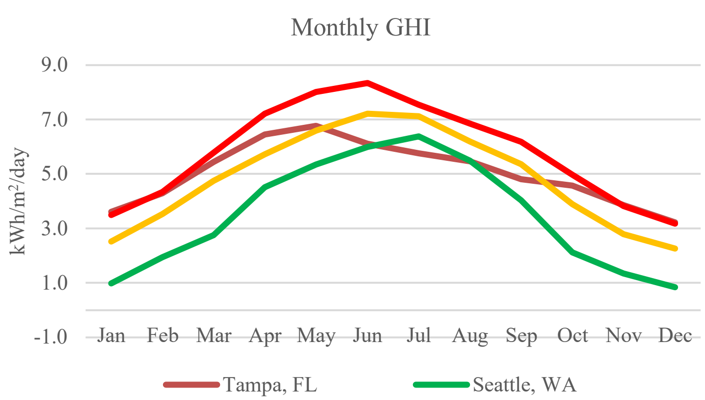
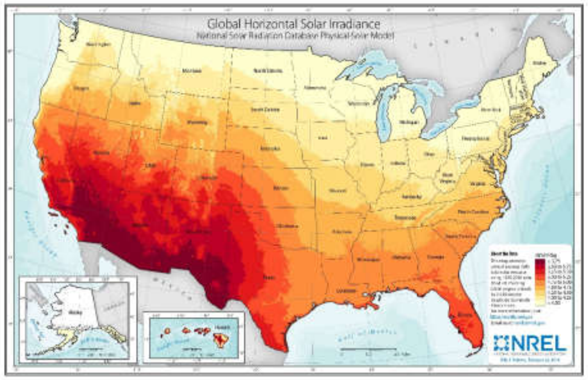
Selection of Locations for Analysis

- Global Horizontal Irradiation: the total amount of radiation received by a horizontal surface
- The study chose the four locations to encompass a broad selection of GHI and latitudes





City	State	Daily GHI (kWh/m2)	Latitude	Longitude
Phoenix	Arizona	>5.75	33.45	-112.06
Denver	Colorado	5.25 – 5.50	39.73	-104.98
Tampa	Florida	5.00 – 5.25	27.93	-82.46
Seattle	Washington	<4.00	47.65	-122.3

PVNB Design Configuration (2)

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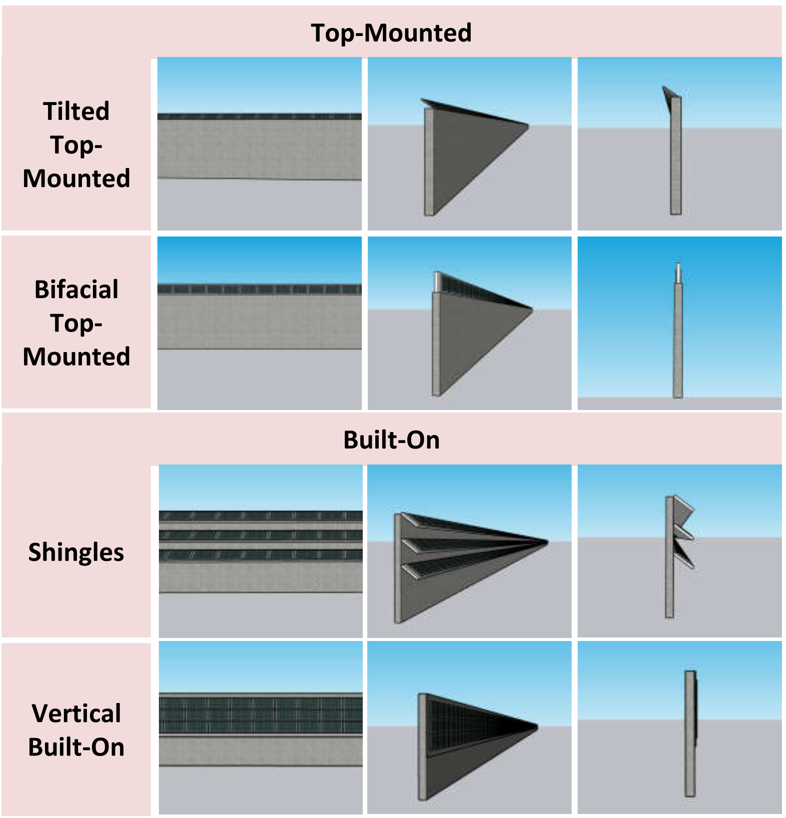
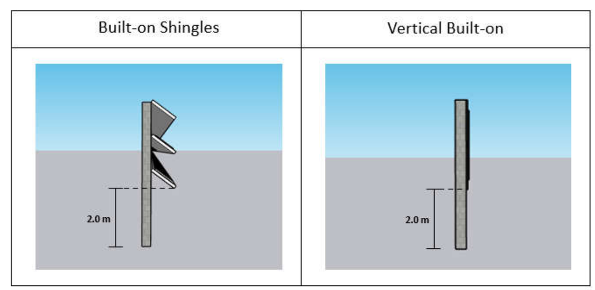


- The barriers are assumed to be 500-m long and 5-m high.
- For built-on configurations (both vertical and shingles) the design has 2-m of free space from the ground to the lowest panel



PVNB Design Configuration (3)

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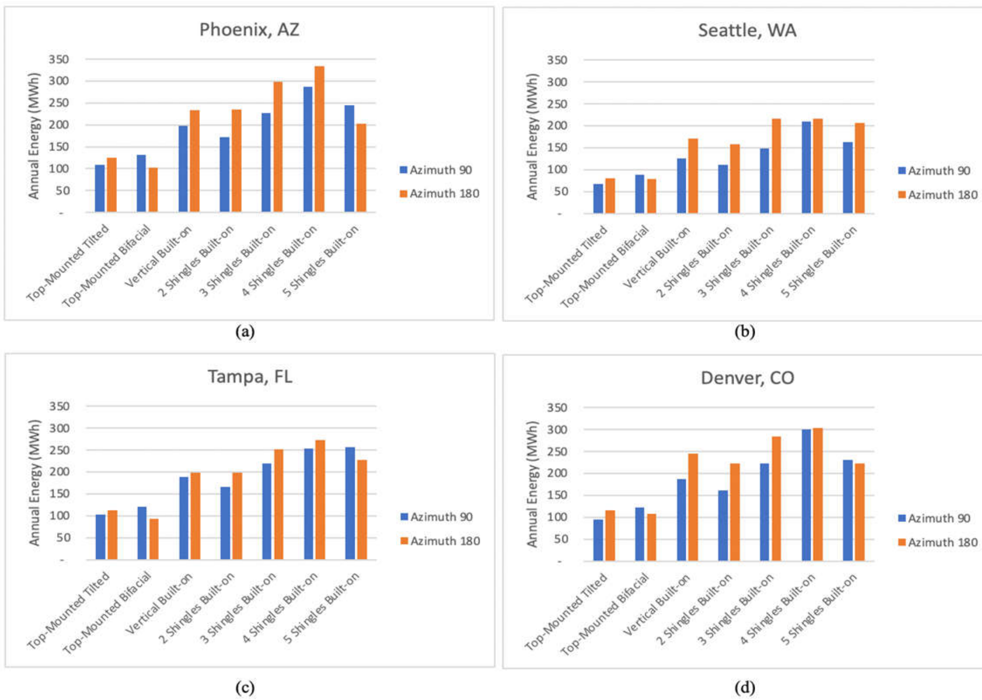
Simulation Results



(a) Phoenix, AZ; (b) Seattle, WA; (c) Tampa, FL; and (d) Denver, CO

PVNB Design Configuration (4)

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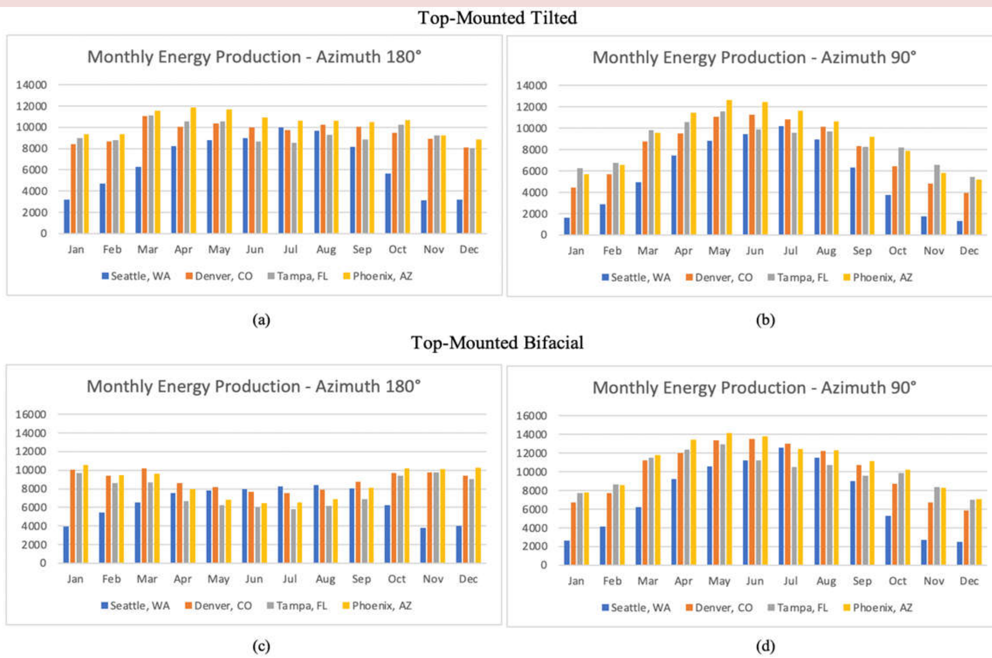
Simulation Results



Monthly energy production for (a) top-mounted tilted PVNB - south; (b)) top-mounted tilted PVNB - east; (c) top-mounted bifacial PVNB - south; and (d) top-mounted bifacial PVNB- east

New Jersey Case Studies (1)

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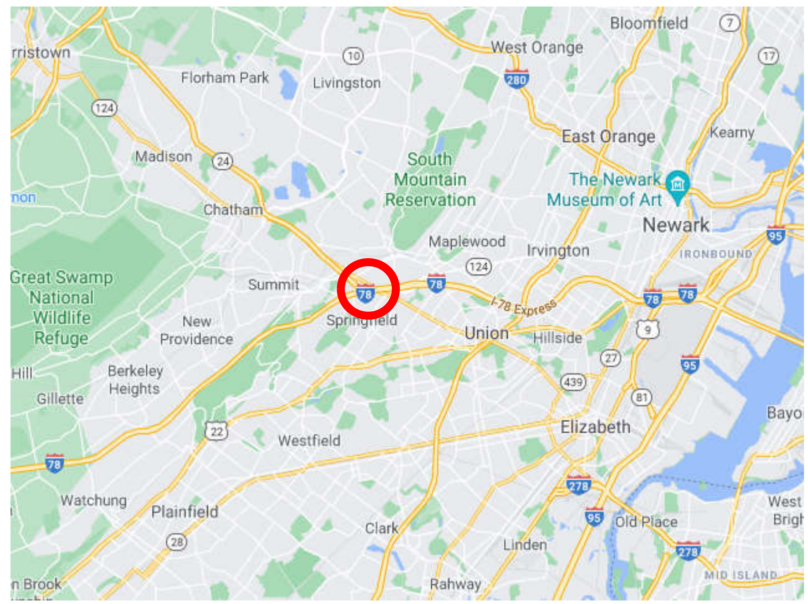
Case Study 1: Springfield, NJ

- Location: Springfield, NJ – I-78 Express
- Azimuth (orientation): 175.5 degrees
- Length: 493 m
- Height: ~ 17 ft (5.18 m)



New Jersey Case Studies (2)

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Case Study 1: Springfield, NJ

Top-mounted Tilted:

- Optimum tilt: 36.7 degrees
- Annual Energy: 98 MWh

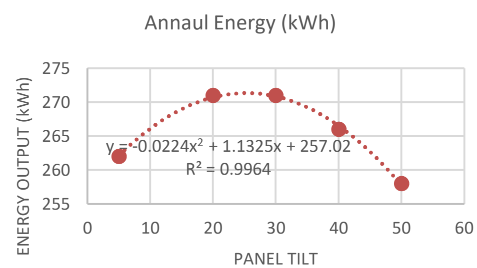
Top-mounted Bifacial:

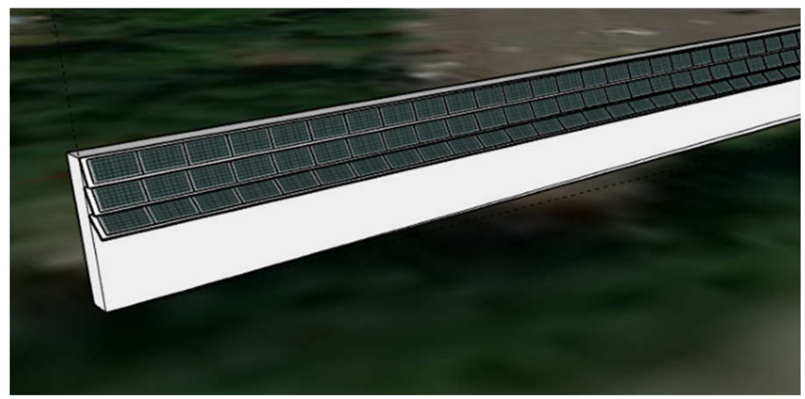
- 90 degrees – harvest energy from both sides
- Annual Energy: 92 MWh

Built in – Shingles

- 3 Shingles on top 3 m of the barrier
- Angles: 70 °, 65 °, and 40°
- Annual Energy: 275.6 MWh

Simulation for a 4kW system:





New Jersey Case Studies (3)

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Case Study 1: Springfield, NJ

Summary:

Configuration	Annual Energy (MWh)	Annual Energy/barrier length (kWh/m)	Annual Energy per square meter (kWh/m2)*	Annual Energy per Panel (kWh)
Top Mounted – Tilted	97.9	198.6	249.0	789.0
Top Mounted – Bifacial	93.4	189.5	118.8	259.6
Built on – 3 Shingles	257.6	522.5	218.4	271.7

* Area of photovoltaic material – bifacial has photovoltaic material in both sides

New Jersey Case Studies (4)

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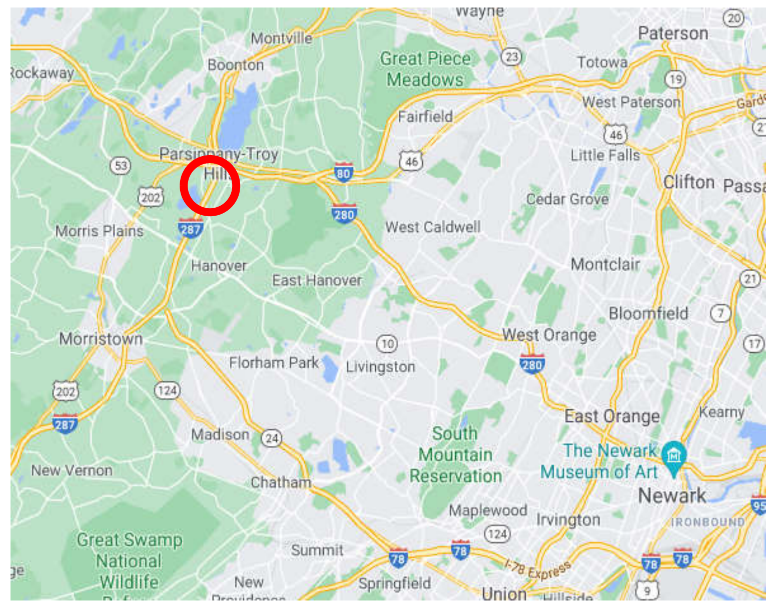
Case Study 2: Parsipanny, NJ

- Location: Parsipanny, NJ – I-287
- Azimuth (orientation): 116.1 degrees
- Length: 1068 m
- Height: ~ 18 ft (5.49 m)



New Jersey Case Studies (5)

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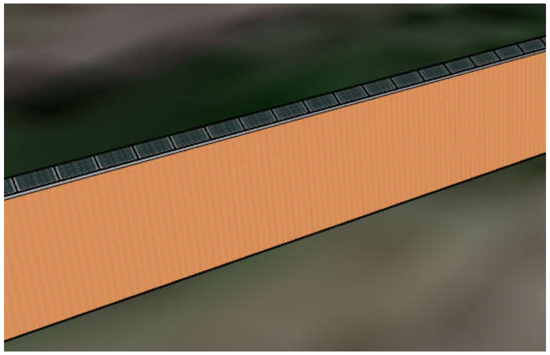
Case Study 2: Parsipanny, NJ

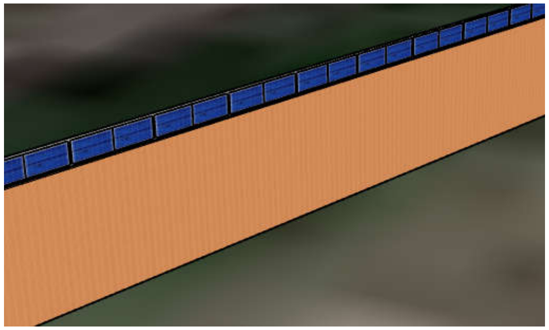
Top-mounted Tilted:

- Optimum tilt: 25.3 degrees
- Annual Energy: 181.6 MWh



Top-mounted Bifacial:

- 90 degrees – harvest energy from both sides
- Annual Energy: 212.6 MWh



New Jersey Case Studies (6)

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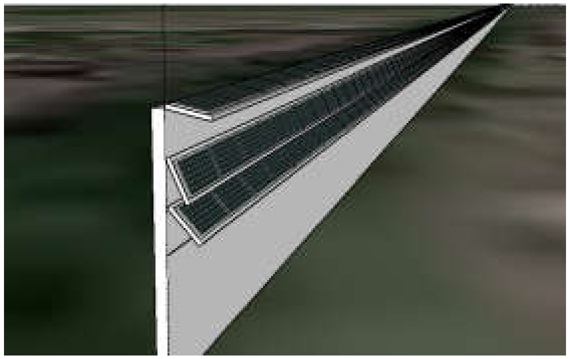
Case Study 2: Parsipanny, NJ

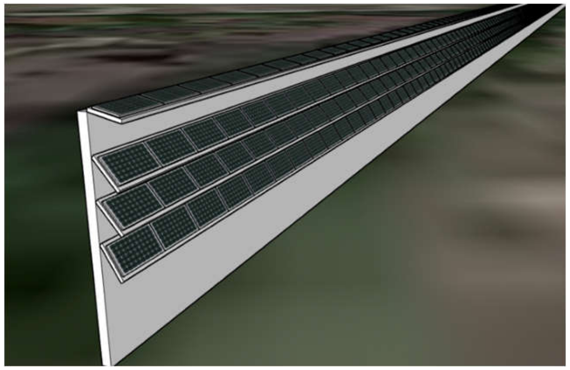
Built in – 3 Shingles

- 3 Shingles on top 3 m of the barrier
- Angles: 10 °, 64 °, and 45°
- Annual Energy: 477.6 MWh



Built in – 4 Shingles

- 4 Shingles on top 4 m of the barrier
- Angles: 10 °, 60 °, 60 °, and 60°
- Annual Energy: 617.9 MWh



New Jersey Case Studies (7)

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Case Study 2: Parsippany, NJ

Summary:

Configuration	Annual Energy (MWh)	Annual Energy/barrier length (kWh/m)	Annual Energy per square meter (kWh/m2)*	Annual Energy per Panel (kWh)
Top Mounted – Tilted	181.6	170.0	213.1	265.1
Top Mounted – Bifacial	212.6	199.1	124.7	310.4
Built on – 3 Shingles	477.6	447.2	186.8	232.4
Built on – 4 Shingles	617.9	578.6	181.3	225.5

* Area of photovoltaic material – bifacial has photovoltaic material in both sides

New Jersey State-level Estimation (1)

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Top-mounted Tilted

1. Find optimum angle for every orientation (20 degrees range)

Simulation of different tilt angles to find polynomial equation and optimum tilt for all direction (varying in 20 degrees)

2. Simulate energy output (kWh/panel) using optimum angle

Simulation using PVWatt of energy output of every orientation using the optimum angle

3. Find Polynomial equation that describes the Energy Output based on the orientation

Find a polynomial equation with R^2>0.95

Top-mounted Bifacial and Built-in Shingles

1. Simulate energy output (kWh/panel) for every orientation (20 degrees range – bifacial/ 10 degrees - shingles)

Simulation bifacial panels using PVWatt of energy output of every orientation

3. Find Polynomial equation that describes the Energy Output based on the orientation

Find a polynomial equation with R^2>0.95

New Jersey State-level Estimation (2)

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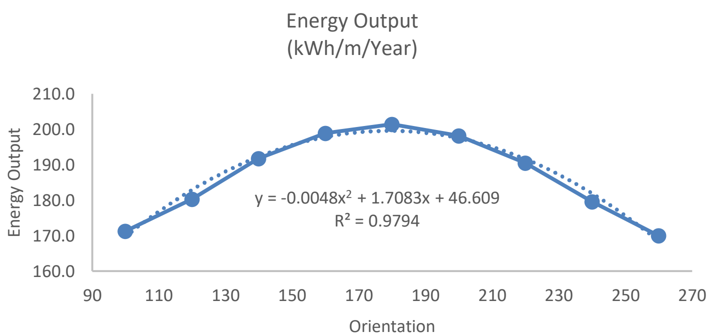
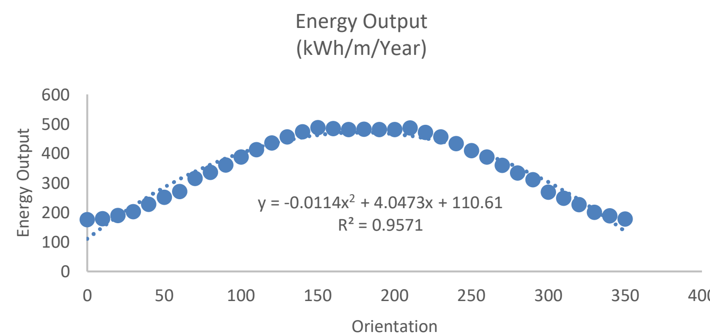
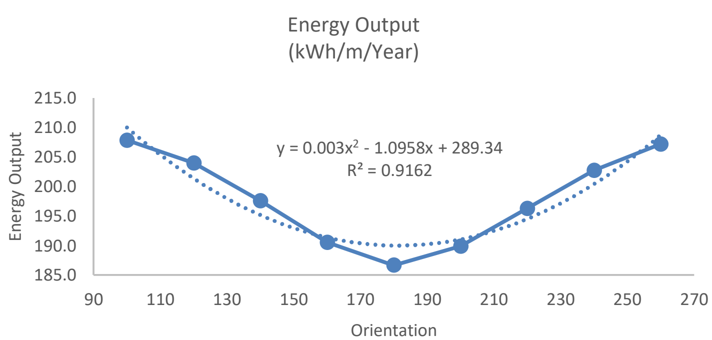
Top-mounted Tilted



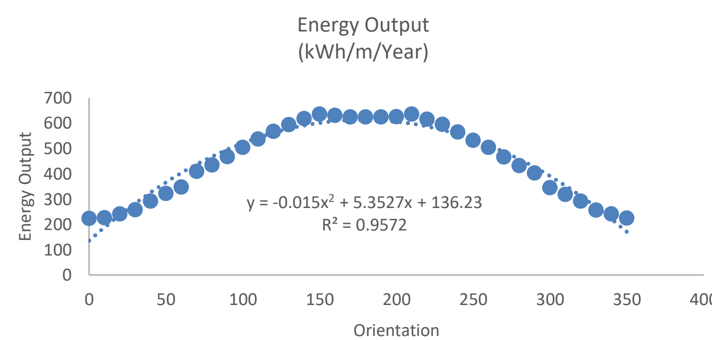
Built-in 3-Shingles



Top-mounted Bifacial



Built-in 4-Shingles



New Jersey State-level Estimation (3)

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Top-mounted Tilted

27,196 MWh/year

- Equivalent to 1,619 miles of streetlight
- 4.2% of NJ public roadways

Built-in 3-Shingles

48,934 MWh/year

- Equivalent to 2,913 miles of streetlight
- 7.5% of NJ public roadways

Top-mounted Bifacial

21,246 MWh/year

- Equivalent to 1,265 miles of streetlight
- 3.2% of NJ public roadways

Built-in 4-Shingles

56,164 MWh/year

- Equivalent to 3,343 miles of streetlight
- 8.6% of NJ public roadways

Findings and Conclusions

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1. Projects aiming for **highest energy** output should prioritize **3- and 4-shingle** configurations
2. Projects prioritizing **cost-benefit** should prioritize **top-mounted** when facing **south,** and **top-mounted bifacial** when facing **east**
3. **Vertical built-on** maybe be selected due to its **aesthetics**, however for energy efficiency or high energy output, other configurations perform better
4. NJ noise barrier study cases results verify the results from the four nation-wide locations study
5. PVNB is a great solution to provide electricity without increasing footprint
6. NJ has potential to provide electricity for **2,390 to 6,310 houses** only using solar energy from PVNB
7. NJDOT can avoid the bill of **3,343 miles** of streetlight (8.6% of NJ public roadway)

Challenges of PVNB Implementation

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- Considering only the electricity benefit, PVNB **cannot fully pay** for the noise barrier
- PVNB issues such as **over-engineered** system **or ineffective** may occur due to the **lack of PV system quality standards** and guidelines
- Inclusion of photovoltaic material does **not benefit** the barrier **acoustically**. Glassy materials tend to reflect and not absorb the noise.
- Safety and security concerns due to the risk of traffic **accidents**, **fire** propagation, **panel damage**, panel **glare**, **driver distraction**, and **snowdrift** in severe weather locations
- **Losses due to soiling** is one of the major issues that decreases the efficiency of PVNB

Future Work

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Future work include the development of a decision-making tool to assist on PVNB implementation.

The tool will predict the energy output of the selected noise barrier and recommend or not the photovoltaic implementation taking into consideration:

- Technical viability
- Social impacts
- Cost-benefit analysis

Acknowledgment

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