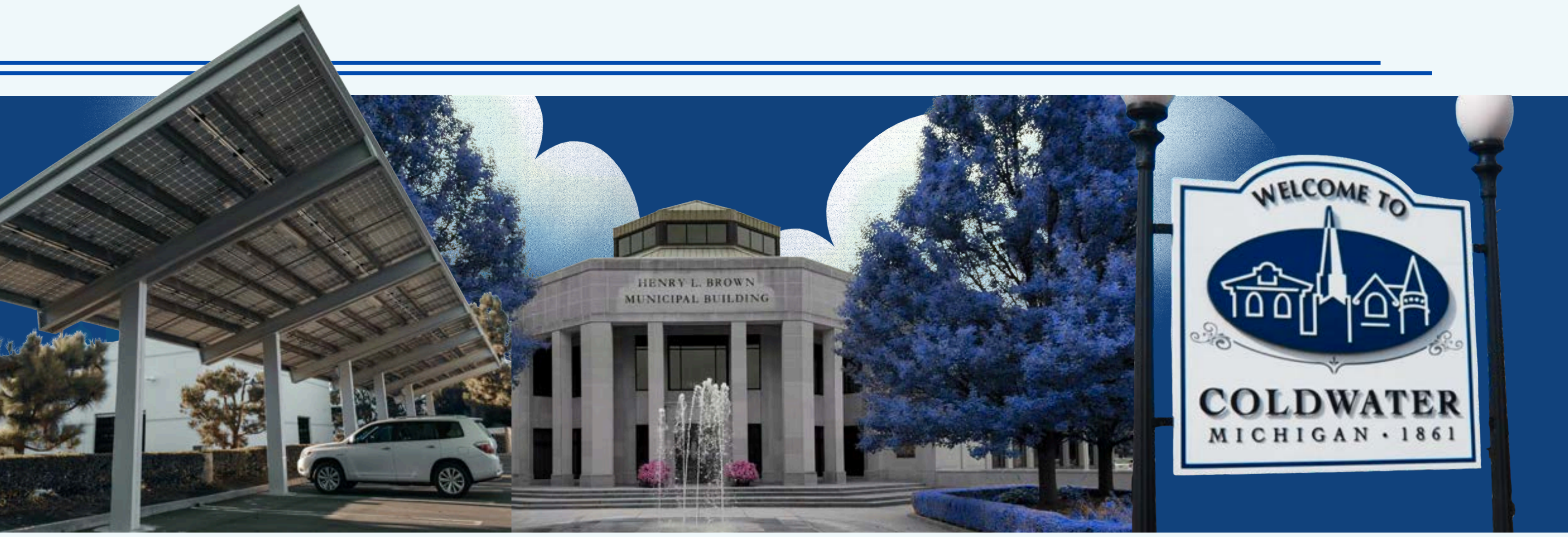
Solar Carport Planning Guide:

A Step-by-Step Guide for Michigan Municipalities & Institutions



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A Step-by-Step Guide for Michigan Communities

Solar carports provide a practical solution for Michigan communities seeking to generate on-site clean energy while maximizing the use of existing infrastructure. By installing elevated solar canopies over parking areas, municipalities and institutions can produce renewable electricity, reduce energy costs, and offer year-round weather protection without consuming additional land.

This guide will walk you through the technical planning process for a solar carport project, including energy performance modeling, site selection, structural and photovoltaic system design, and important financial and economic factors specific to Michigan.

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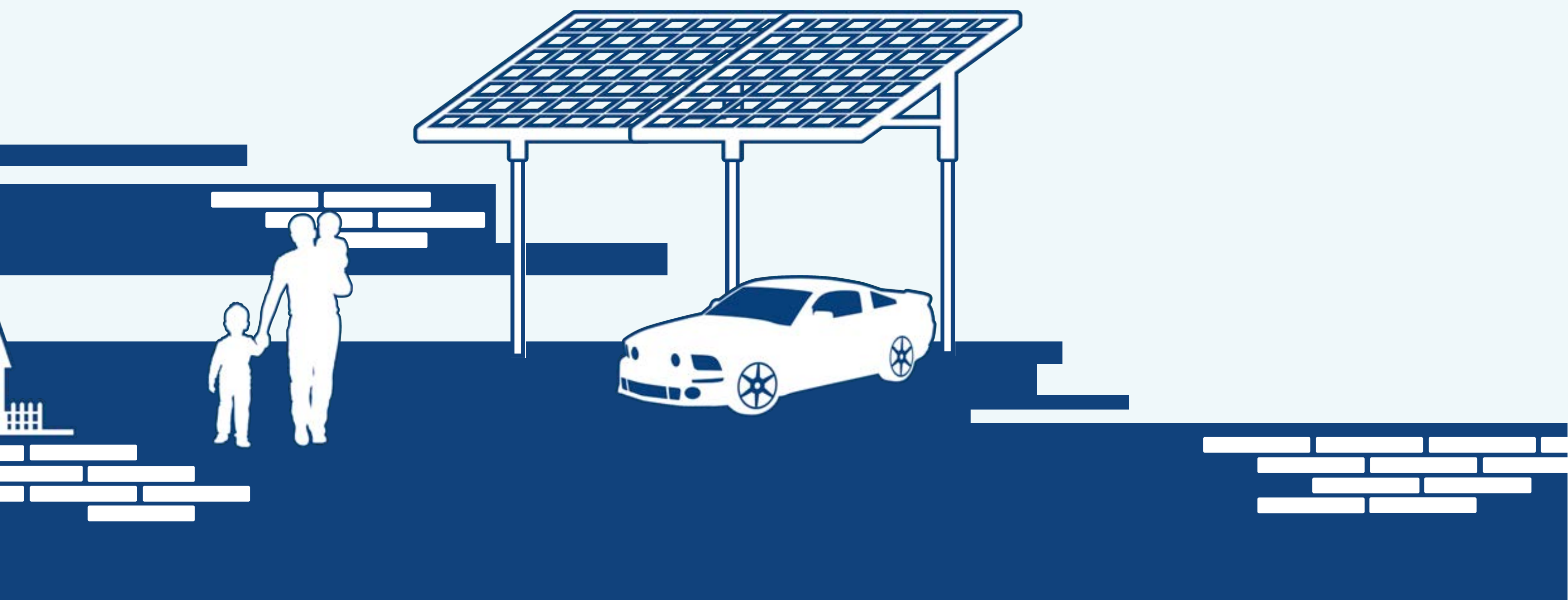
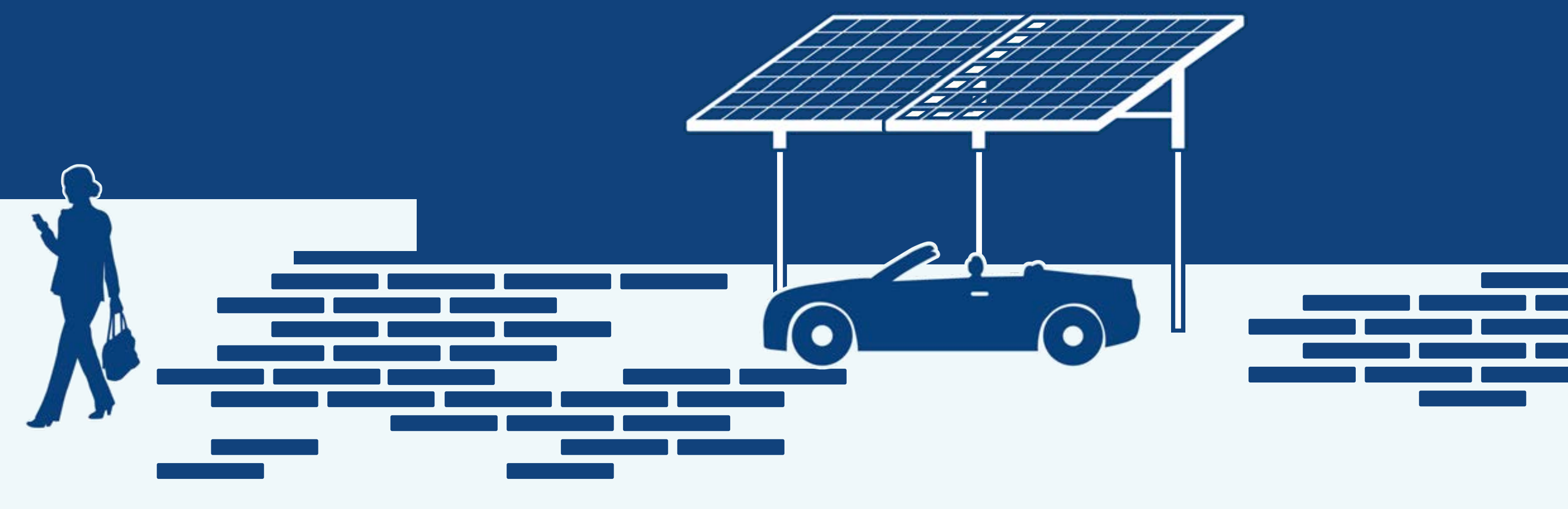


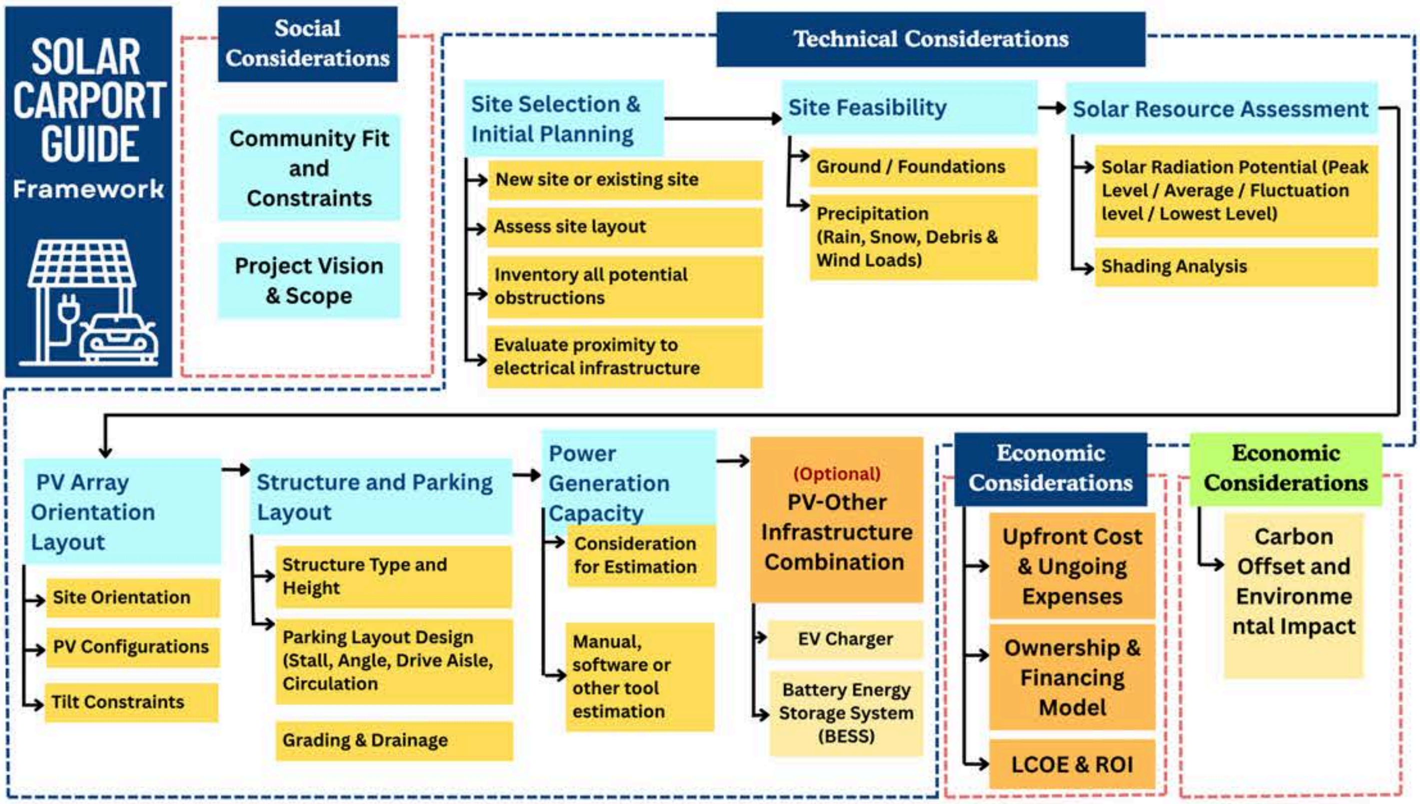
Contents

Disclaimer: This guide is intended for informational and educational purposes only. It does not replace the need for expert evaluations or services, even though it provides a general overview of the procedures and factors to be taken into account when creating a solar carport project. To ensure compliance with structural, electrical, and zoning rules, readers should seek advice from professional engineers, solar contractors, and local permitting authorities for systems that are bigger in scope or technically complicated.



Solar Carport Guide – At a Glance

This guide provides a practical roadmap for municipalities and organizations exploring solar carports. It condenses key considerations—social, technical, economic, and environmental—into an accessible framework. From site selection to community engagement and financial modeling, it highlights how to evaluate, plan, and implement solar carport projects for both energy generation and community benefit.



Social Considerations (Why & Who Benefits), Before technical design begins, projects must align with community needs:

- **Community Fit & Constraints:** Identify **beneficiaries** (residents, staff, underserved groups) and address zoning, accessibility, and visibility.
- **Project Vision & Scope:** Determine whether the carport **supports resilience** (EV charging, public education) or **dual purposes** like markets or emergency hubs.

Technical Considerations – Summary, to ensure a solar carport is both functional and efficient, planners must evaluate the site and system with three key steps:

Site Selection & Initial Planning

- Identify if the location is a **new** or **existing site**. Review the parking layout and
- Evaluate **potential obstructions** like trees, buildings, or signage.

Site Feasibility

- Assess **ground conditions** and **foundatio**n needs to support canopies.
- Account for **precipitation factors**, including rain, snow accumulation, wind loads, and debris impacts, which affect structural design.

Solar Resource Assessment

- Measure the site's **solar radiation potential,** considering peak, average, and seasonal fluctuations
- Perform a **shading analysis** to avoid production losses and confirm optimal panel locations.

PV Array Orientation & Layout

- Determine site orientation for the canopy.
- Select between **south-facing (north-south canopies)** or **east-west** configurations based on available sunlight and land use.
- Apply **tilt constraints** to balance energy capture, snow shedding, and structural stability.

Structure & Parking Layout

- Finalize canopy type, height, stall dimensions, drive aisle width, and vehicle circulation.
- Incorporate grading and drainage to prevent water pooling and maintain site usability.

Power Generation Capacity

- Estimate energy production using **manual calculations, modeling tools, or simulation software** to match demand and optimize ROI.

PV-Other Infrastructure Combinations (Optional)

- Evaluate integration with **EV chargers** or **Battery Energy Storage Systems (BESS)** to increase functionality and grid flexibility.

These steps create the foundation for informed design decisions, guiding **array orientation (south-facing vs. east-west), tilt angles, and system sizing** to ensure reliable energy production and long-term performance.

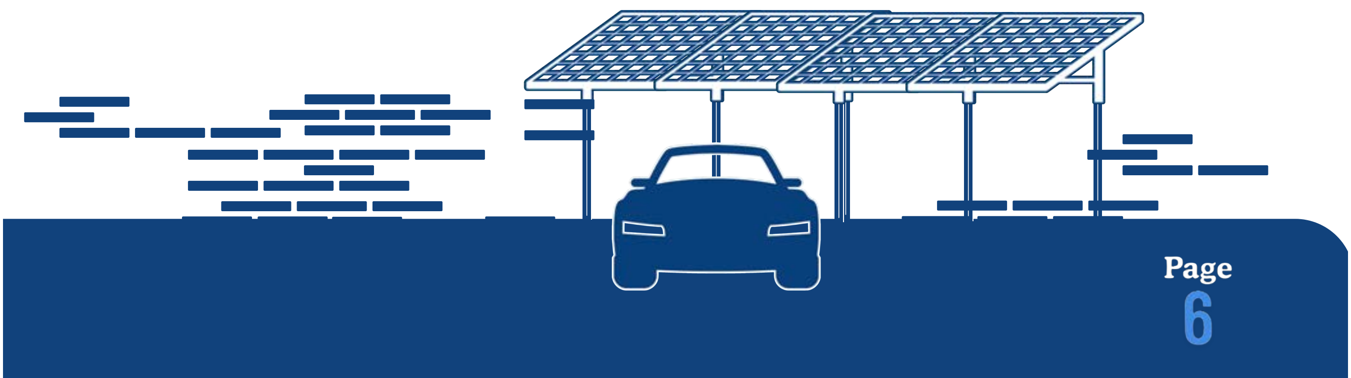
Economic Considerations (Cost & Return)

- **Upfront Cost & Ongoing Maintenance:** Understand structural, electrical, and permitting costs, and annual O&M (operations and maintenance).
- **Ownership & Financing Models:** Compare municipal ownership, Power Purchase Agreements (PPAs), or third-party financing.
- **LCOE & ROI:** Evaluate long-term cost-effectiveness and payback timelines using tools like PVWatts and SAM.

Environmental Considerations (Why It Matters Beyond Dollars)

- **Carbon Offset & Environmental Impact:** Quantify avoided CO_2 using tools like the EPA Greenhouse Gas Equivalencies Calculator. A typical municipal carport can offset 100+ metric tons of CO_2 per year—equivalent to removing dozens of cars or powering multiple homes annually.

This framework simplifies the solar carport planning process, offering a structured way to evaluate opportunities while balancing cost, performance, and community impact. Each section of the full guide expands on these topics with tools, examples, and best practices (see full document for tables, resources, and appendices).



Social Considerations

This section focuses on how solar carports fit within a community's priorities, visibility, and needs. Beyond technical and financial aspects, understanding the social context ensures projects gain public support and deliver real benefits. The questions and steps below can help communities assess their alignment with local goals, identify potential beneficiaries, and identify any physical or social barriers to implementation.

Step 1: Community Fit and Constraints

Before identifying a location or technical approach, think about how the solar carport aligns with your or your community's values, visibility, and practical limitations. These social considerations help ensure the project earns support and meets real needs. Several key questions could guide your decision, such as:

- **Who will benefit?** Will it serve you, the general public, specific residents, staff, or underserved groups?
- **Will it be visible and accessible?** Sites like city halls, libraries, or schools can spark awareness and pride.
- **Does it reflect community values?** Could it double as a site for EV charging, farmers' markets, or emergency hubs?
- **Are there physical or social constraints?** Consider zoning rules, space competition, shading from trees, or local concerns.
- **Will it support broader goals like resilience or public education?**

Step 2: Project Vision and Scope

Once the community context is considered, define the project's purpose and scope. Knowing the technical intention will guide key planning decisions, such as layout and design.

Clarify the project's main objectives:

- Maximize renewable energy generation
- Provide shaded or weather-protected parking
- Support EV infrastructure
- Act as a public education tool or climate action symbol

Determine the project's size based on your goals, budget, and available space:

- **Small-scale installation**, such as a single canopy or part of a parking lot
- **Mid-scale installation**, for a particular building or high-traffic area
- **Larger-scale or phased project,** with room to expand over time

Technical Consideration

This section highlights the technical factors that municipalities and organizations should consider before proceeding with a solar carport project. It covers key aspects such as site selection, system orientation, structural design, and environmental conditions, helping ensure that the carport operates efficiently, remains durable, and meets community needs throughout its lifespan. These considerations are designed to inform early planning and help minimize costly adjustments during construction and operation.

Step 1: Site Selection and Initial Planning

Before a solar carport is installed, careful site planning is necessary. Choosing the ideal site and being aware of the technical and physical limitations of the site are critical to the project's success, effectiveness, and long-term sustainability.

- **Existing Lot vs. New Project.** Take into account whether the project is a part of a new development or is built onto an existing parking lot. While new projects offer more flexibility to optimize layout, existing lots may have fixed layouts, existing lighting poles, and other potential constraints.

- **Create a map of the site's layout.** The arrangement of parking rows, drive aisles, curbs, adjacent structures, and pedestrian walkways should all be considered. A clear visual of the existing layout will help identify design constraints and opportunities.

- **Create an Inventory of all potential obstructions.** Typical examples are light poles, street or facility signage, security cameras, tall trees, and building overhangs. These components might restrict the locations where arrays can be set up or cause structural or shading problems that could impair system performance.

- **Proximity to Electrical Infrastructure.** Verify the electrical infrastructure's accessibility. Determine whether the location is close to any existing electrical connections, such as utility lines or the electrical room of a building. Additionally, sites with lighting or EV charging stations may already have useful electrical conduit in place.

- **Assess ground and surface conditions.** Identify the type of soil, surface quality, and drainage, and whether it is suitable for foundations, particularly in areas like Michigan that experience freeze-thaw cycles. [1] Determine whether underground utilities (such as fiber optic cables, water pipes, and electric lines) are present. When retrofitting, consider pavement conditions, as they will impact conduit runs, trenching, and installation techniques.

- **Consider precipitation and seasonal weather impacts (e.g., snow load, runoff).** Michigan has unpredictable seasonal changes throughout the year, having cold winters and hot summers, because the variety of loads could impact the solar carport's performance. [2]

Step 2: Solar Resource Assessment

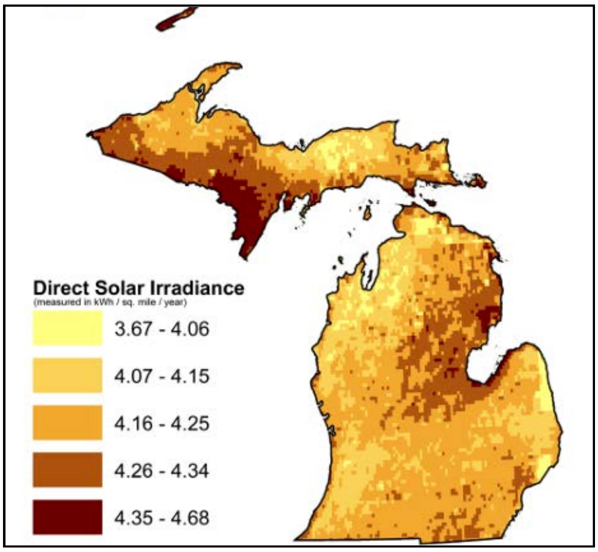


Figure 1. Direct Solar Irradiance Across Michigan (kWh/m²/year) [3]

Michigan's solar resource potential varies across the state, with darker orange regions showing areas of higher solar irradiance and lighter yellow regions indicating lower availability. These values represent the annual solar energy capture potential of different areas. However, since Michigan is situated near the Great Lakes, it is prone to the lake-effect, which causes clouds and snow to be more prominent, especially during the colder months. [4] Even though Michigan is not the sunniest place in the United States, and it might not be comparable to the southwestern states, Michigan is still full of potential. [5] This section outlines the aspects that need to be considered to evaluate the solar resources available to utilize within our system.

- **Assess solar exposure across seasons.** Evaluate the solar exposure within the potential location across different seasons. Emphasis should be put on the summertime for peak solar exposure and the wintertime for the lowest solar exposure. [6] Additionally, for a highly accurate prediction, it is recommended to evaluate solar exposure on a yearly basis, as rapid climate change is affecting several areas at varying rates. Several databases for solar irradiance are available to the public, as referenced in **Appendix 2.**

- **Assess Solar Exposure and Shading.** Identify parking lots or areas that receive abundant sunlight, particularly in the middle of the morning and late afternoon. [7] Because shading on panels can significantly reduce energy output, ideally, steer clear of locations with buildings or trees that cast large shadows over the parking area. [8] Additionally, conduct a shading analysis evaluating simple satellite images or a more comprehensive analysis using tools such as those referenced in **Appendix 2.**

Step 3: PV Array Orientation, Configuration, and Tilt Considerations

Orientation

Evaluate the orientation of parking rows early in the design process, consider how the parking rows should be oriented, and how solar panels are positioned. This is because effectively capturing the sunlight will depend on whether the rows are aligned east-west or north-south. [9]

- **East-west-oriented rows** offer chances to align panels with the sun's path, which frequently results in more direct solar exposure all day long.
- **North-south-oriented rows** might limit direct south-facing panel placement but can still accommodate effective solar layouts that distribute generation across the morning and afternoon hours.

PV Configuration

The structural configuration of the canopy influences how the array integrates with the parking lot, affects visual and spatial design, and sets the foundation for later decisions like tilt and drainage. Each configuration has implications for performance, cost, and construction complexity. The choice should be guided by the site's orientation, available space, aesthetic goals, and functional requirements such as vehicle clearance and parking layout. The type of configurations are as follows:

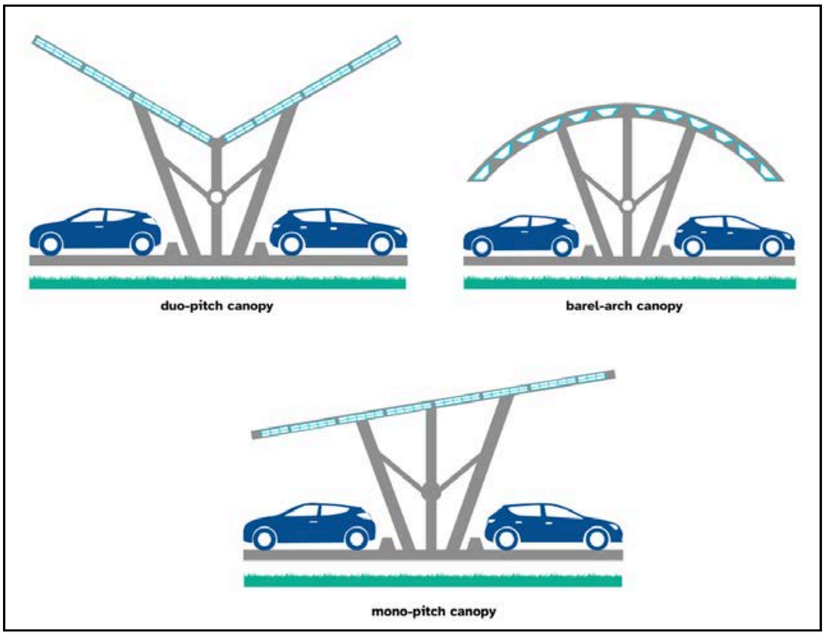


figure 2. Type of PV Configurations [10]

Mono-pitch (Single-Slope)

All panels are tilted one way, usually facing the equator (south-facing in the Northern Hemisphere). This is essentially like a slanted shed roof over the parking. Monopitch canopies are often used when covering a single row of parking or when rows run east-west.

Advantages: It provides a simple structure, often used to maximize sunlight in one direction. Only one edge will shed water and other loads, so gutters or drainage systems may be simpler than those of other types. Monopitch PV systems facing south typically produce the highest energy output compared to different types of configurations.

Trade Offs: For a wider or larger scale of canopy, it may not be as aesthetically pleasing compared to other structures. If a monopitch system faces north to east, its output can be lower than that of a duopitch in any direction.

Duo-pitch (Double-Slope or "Gull-Wing")

A canopy with two sloped surfaces that meet at a center ridge or valley, forming an inverted "V" shape.

Advantages: Captures sunlight during both morning and afternoon hours, producing a broad and balanced generation curve; Well-suited for north-south parking rows where true south-facing panels are not feasible; Offers a clean, symmetrical aesthetic over double rows.

Trade-offs: Slightly lower total annual energy output compared to optimal south-facing monopitch designs (typically ~90–95%). Requires a central valley, which must be engineered to handle snow and water drainage, especially in climates with heavy winter precipitation.

Other Configurations

Alternative designs, such as curved (barrel-arch) or flat-roof canopies, are typically chosen for architectural or site-specific reasons. These designs may prioritize aesthetics, match existing structures, or respond to spatial constraints. While less common, they can be viable options when integrated thoughtfully into the overall site plan.

Tilt

Setting a photovoltaic array at the optimal angle is also one of the best ways to maximize its energy output. [11] To optimize solar panel performance, selecting the appropriate tilt angle is crucial, especially in regions like Michigan that are known for their significant snow, wind, and rain load. The tilt angle directly affects the incident solar radiation received throughout the year, influencing energy yield. Panels that are too flat underperform in winter due to low sun angles and snow accumulation, while excessively steep panels can reduce annual output by underutilizing the summer sun. Generally, in snowy regions like Michigan, a slightly steeper tilt (e.g., 20–40°) not only improves winter output but also helps snow slide off, minimizing soiling losses. [12]

However, since our goal is to build a fully functional solar carport, other than the optimization, we also have to consider the functionality of the canopy and whether it fully covers and protects the vehicles underneath it. Therefore, during the simulations to decide on the exact tilt angle, it is recommended to try out adjusting different tilts based on local solar path data and monthly irradiation levels, or using a region-specific clustering model to generalize optimal angles.

Step 4: Structure and Parking Layout

Solar carports must be structurally sound, durable, and compliant with local building codes. Especially in regions like Michigan, with heavy snow and wind, loads should comply with the relevant building code. This section outlines the core structural options and key design considerations, including frame style, foundation system, parking layout, and other relevant factors.

Structural Frame Type and Height

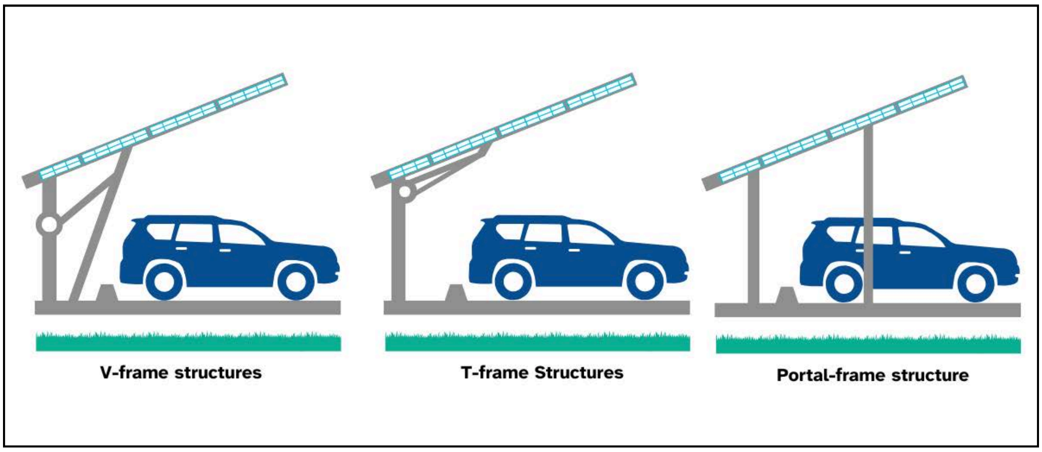


figure 3. Type of PV Configurations

structure type

Frame Structure
refers to the column and beam arrangement supporting the solar panels overhead. Three common structural frame styles are T-frame, V-frame, and portal frame (goalpost), each with pros and cons, [13] such as:

T-frame
Uses a single row of central columns with cantilevered beams forming a "T" shape. The columns typically sit at the back of parking stalls (along the drive aisle or midpoint of a double-row), supporting a canopy that overhangs on both sides.

Advantage: Keeps columns to a minimum and out of the way of car doors and driving lanes.

Trade-offs: Requires heavier beams to cantilever the panels, increasing steel usage and cost. T-frames are reported to cost roughly 10% more than V-frames of similar size due to the larger overhanging structure. They may also need deeper foundations or counterweights to handle the unbalanced load.

V-frame
Uses two angled supports per span, forming a "V" shape (often one vertical column near the drive aisle and one diagonal column toward the parking space side). This design usually aligns the supports at the edges of parking stalls (between two cars).

Advantage: Very material-efficient, which makes it the most cost-effective frame for a large carport. The diagonal strut maintains stability, which in turn makes the beams lighter. It also makes it easy to put things like inverters on the column.

Trade-off: The diagonal columns can protrude slightly into the corners of parking spaces, so the layout must ensure they don't block car doors or impede vehicle maneuverability. People often use protective bollards to prevent collisions.

Portal frame (double-column)
It has two vertical columns, one on each side of the span, that make a stiff rectangular "goalpost" shape. These frames often span multiple rows and can support flat, arched, or duopitch roofs.

Advantage: Very strong and stable, ideal for covering large areas with a continuous canopy. The design can reduce the number of structures required to span a large area and offers flexibility in roof shapes.

Trade-off: Requires more steel and larger footings, leading to higher material costs. The two columns per span, particularly those near drive aisles, can make maneuvering difficult for larger vehicles. While they maximize coverage, they're generally more expensive per structure.

Frame height

Although a solar carport is heavily reliant on the frame support, this structure must not interfere with vehicle movement or access; it should complement the PV Array and parking size and configurations. Several considerations must be taken into account, and these depend on the type of vehicles that will be housed underneath the structure, as well as whether the carport is used for private or public property. These are the following considerations:

Design Element	Recommended average	Notes
Standard Residential carport	8 ~ 12 ft	Standard SUV and RV
Standard Commercial Carport	12 ft ~ 16 ft	Larger vehicles, such as trucks
Vertical Clearance for an Emergency Vehicle	14 ft	Required for emergency vehicles (per IFC 503.2.1, UA Guidelines)
Vertical Clearance for Delivery Bays	16 ft	For service or freight access
Column Placement	≥ 3 ft from drive aisle edge	Avoid the inside stall envelope, allowing safe maneuverability

Table 1. Recommended Frame Height and Column Standards for Solar Carports [14], [15], [16]

Parking Layout Design

When designing a solar-integrated parking lot, the layout must satisfy both the needs of vehicle circulation and the requirements of the solar infrastructure. There are relevant design standards that we should ensure we comply with to meet best practices and regulatory requirements. Those requirements that need to be considered are as follows:

Parking Stall

A parking stall is the designated space for each vehicle. Dimensions vary based on the stall angle and vehicle type. There are several typical parking stalls, such as the following:

Stall Type	Width	Depth (Perpendicular to Curb)	Notes
Compact Vehicle Stall	8.0–8.5 ft	Varies by angle	Typically used in high-density lots or limited space scenarios
Standard Vehicle Stall	9.0 ft (typical)	18 ft at 90°	Industry norm for standard parking configurations
Angled Stall	9.0 ft	17–20 ft	Depth varies with angle (see Table X)

Table 2. Standard Angled Parking Dimensions [17] [18]

Parking Angles and Stall Efficiency

The angle at which parking stalls are arranged impacts land use efficiency, ease of maneuvering, and aisle requirements. Industry guidelines emphasize adjusting aisle width based on stall orientation and traffic direction.[19], [20]Although it is sometimes common for people not to follow these standards, the following reference is handy for integrating angled parking layouts into solar carport designs, ensuring both vehicle functionality and optimal canopy span. The table and figure below present standard angled parking dimensions commonly used in design guidelines.

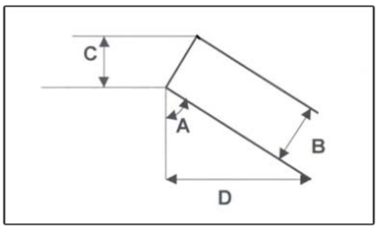


Figure 3. Key Parameters for Angled Parking Layout

Parking Angle	Stall Width (B)	Curb Length (C)	Stall Depth (D)	Stripe Length (G)	Aisle Width (E)One-Way	Section Width (F)One-Way	Aisle Width (E)Two-Way	Section Width (F)Two-Way
	ft (m)	ft (m)	ft (m)	ft (m)	ft (m)	ft (m)	ft (m)	ft (m)
30°	8.5 (2.59)	17 (5.18)	16.4 (5.00)	32.7 (9.97)	12 (3.66)	44.7 (13.62)	24 (7.32)	56.7 (17.29)
45°	8.5 (2.59)	12 (3.66)	18.7 (5.70)	26.5 (8.08)	14 (4.27)	51.4 (15.67)	24 (7.32)	61.4 (18.72)
60°	8.5 (2.59)	9.8 (2.99)	19.8 (6.04)	22.9 (6.98)	16 (4.88)	55.6 (16.95)	24 (7.32)	63.6 (19.39)
90°	8.5 (2.59)	8.5 (2.59)	18 (5.49)	18 (5.49)	22 (6.71)	58 (17.68)	24 (7.32)	60 (18.29)

Table 3. Standard Angled Parking Dimensions in Feet and Meters

Angle	Curb Length per Stall	Notes
30°	~18 ft	Easy entry/exit but less space-efficient
45°	~12.5 ft	Balanced design, commonly used
60°	~10.5 ft	Higher capacity, requires deeper stalls
90°	~9 ft	Maximizes total stall count; needs wider aisles

Table 3. Summary of Curb Length and Design Implications by Angle [21],[22]

Grading and Drainage

Proper grading is essential to ensure safe, functional, and code-compliant parking lot design. Effective slope planning helps prevent water pooling, protects electrical components like inverters and conduit systems, and maintains accessibility for all users. This is especially critical for solar carport installations, where surface runoff must be directed away from sensitive equipment while meeting the slope limits requirements. The table below outlines recommended slope ranges for key areas of the site.

Area	Slope Guideline
General Pavement	1–5% longitudinal, 1–2% cross slope
ADA Stalls & Routes	≤ 2.08% in any direction
Surface Runoff	~2% slope recommended toward drains

Table 4. Slope Guidelines for Parking Surfaces and Accessible Routes [23]

Step 5: Power Generation Estimation

After deciding on the design arrangement of your desired PV array based on existing spaces and other factors, it is now time to complete the most crucial aspect of analyzing your solar carport, which is estimating the power provided by your solar carport. The goal is to translate the intended array (kW) and site irradiance into annual energy production (kWh). This stage will consider peak, average, and minimum insolation to provide an accurate estimate of generation. In this step, we can apply simple calculations or use PV performance model tools or software to get a more accurate estimate.

Consideration for Estimation

Loss factors account for system losses (inverter efficiency, soiling, shading margins). It is recommended to apply standard derating factors to adjust the ideal output down to a realistic value. The values that need to be factored in, for example, are as follows:

Loss Category	Description	Typical Loss (%)
Shading Losses	Shadows from nearby trees, buildings, or poles. Designed to be minimal for carports, but even partial shade can impact output.	~7%
Soiling Losses	Dirt, dust, bird droppings, and snow on panels reduce efficiency. Michigan's snow may cause seasonal dips until cleared.	~2% (rainy regions); higher with snow
Reflection & Angle Losses	Some sunlight reflects off glass instead of being absorbed. Suboptimal angles (e.g., not perpendicular to the sun) reduce effective irradiance.	~2–3%
Electrical & Thermal Losses	Resistance in wires (~1%), module mismatch, and heat derating (typically -0.5%/°C above 25°C). Michigan's moderate temperatures help reduce this.	~1–3%
Inverter Losses	Conversion of DC to AC is not 100% efficient. Most modern inverters operate at 95–98% efficiency.	~2–5%
Downtime/ Maintenance Losses	Scheduled maintenance, unexpected outages, or monitoring failures can temporarily reduce output.	~2% annually
Panel Degradation	Over time, solar panels lose efficiency. Most panels degrade ~0.5–1% per year, depending on quality.	~0.5–1% annually

Table 5. Summary of Common Solar PV System Losses and Estimated Impact on Energy Output [24], [25]

Manual Estimation

Manually, we could apply an overall derate factor to account for these losses. NREL's PVWatts uses a default 14% total system loss assumption to cover average effects of soiling, shading, wiring, inverter inefficiency, etc. [26] There is a common formula used to calculate the size of a solar PV array that we could refer to the calculation below:

Annual Energy Output (kWh/year) =

System Size (kW_dc) × **Solar Resource (kWh/kW/year)** × **Performance Factor**

Where:

- *System Size* = total installed DC capacity of the PV system
- *Solar Resource* = average annual solar irradiance per kW in your location (e.g., ~1,200 kWh/kW/year for Michigan)
- *Performance Factor* = derating multiplier to account for system losses (typically ~0.86 for ~14% total losses)

Case Example: A municipality in southern Michigan is exploring the installation of a 100 kW solar carport to reduce utility costs and advance local sustainability goals. Located in a region that receives approximately 1,200 kWh per kilowatt of solar capacity per year, equivalent to 4 to 4.5 peak sun-hours per day.

Solution:

100 kW × 1,200 kWh/kW/year = 120,000 kWh/year

However, accounting for typical performance losses such as shading, snow cover, inverter inefficiencies, and panel soiling, we apply a performance factor of 0.86 (i.e., 14% loss), giving us:

100 kW × 1,200 × 0.86 = ~103,200 kWh/year

In real-world conditions, using this simple estimation, the carport is expected to produce 100,000 to 105,000 kWh per year, depending on seasonal variation and specific site characteristics.

Software and other tools Estimation

In general, although it is possible to calculate them manually, utilizing software tools can significantly enhance accuracy and ease in solar production estimates. A typical example that people generally use is NREL's PVWatts Calculator, a free online tool that estimates the energy production of grid-connected PV systems worldwide. There are also other types of tools referenced in **Appendix 2**. Typically, these tools feature a comprehensive database of local typical meteorological year data for the designated area, including typical cloud cover, temperature, and sunlight hours for the region. Then we can customize the orientation, system size, and tilt, and other components, the outcome is usually a month-by-month and annual energy output estimation.

For more complex carport projects, especially those involving non-standard designs or shading considerations, more advanced PV software can also be used. A more comprehensive tool usually includes detailed 3D modelling of the carport structure, nearby trees/buildings, and can simulate hourly performance. These software platforms consider factors such as the sun's path across the sky, shading at different times of day, snow coverage (if data is provided), and detailed component specifications. Such detailed tools are helpful when precision is needed for final system design or financing; however, they require more expertise.

Step 5: *Integrating Additional Infrastructure with Solar Carports*

This step is considered optional depending on the user's preference and needs. Modern solar carport projects can incorporate EV charging stations, battery storage, and other infrastructure, creating an integrated system overall. Each combination adds value, from reducing transportation emissions to providing backup power, but also comes with planning and technical considerations. Below is an overview of these forward-looking options, along with key considerations to keep in mind when pursuing them.

EV Charging Stations

This is an emerging combination as EV adoption is growing in Michigan. Pairing solar carports with EV charging infrastructure is a common combination where the solar panels can directly offset the electricity used by EV chargers, allowing vehicles to be powered by clean energy captured on-site. [27] Key considerations that need to be considered include:

Site Layout and User Convenience

The carport design should allocate space for charging stations, including protective bollards and clear signage, to ensure user convenience. Often, EV charging spots are placed at the front row under the canopy for visibility and ease of access. Ensure that the charger cable reach and parking layout are convenient for users. In the context of Michigan, remember to accommodate winter conditions. Chargers and their cables should be located where snow removal equipment won't damage them. Sheltered placement under the carport roof can help keep charging equipment free of snow/ice.

Energy Balance and Electrical Planning

Solar carports naturally align with workday parking hours, allowing midday solar production to power EV charging when demand is highest. While this covers much of the daytime load, cloudy days or late afternoon use may still require grid power, especially for fast chargers with higher energy needs. Users should assess peak charging demand and confirm that the electrical capacity is sufficient to handle simultaneous charging. Decide whether EV chargers will share the same meter as the solar array (for net load offset) or be separately metered (for public use or rebates). [28]

Permitting and Incentives

Installing EV chargers typically requires electrical permits and inspections. It is wise to consult local codes regarding parking lot modifications.

Battery Energy Storage System (BESS)

Adding BESS to a solar carport installation can dramatically increase the flexibility and resilience of the energy system.[29] In Michigan, where peak electricity usage and utility demand charges might be concerns for commercial facilities, a battery can store excess solar power and discharge it when most needed (for example, on winter late afternoons or during a grid outage). Key considerations for integrating battery storage include:

Use Case and Sizing

Integrating a Battery Energy Storage System (BESS) allows solar carports to serve multiple functions, such as providing backup power during grid outages, reducing peak demand charges, or supporting EV charging during high-use periods. In Michigan, where winter loads and commercial demand costs can be high, even a modest-sized battery can store midday solar to support several hours of critical use later. Larger systems (e.g., 500+ kWh) can support essential building loads or widespread EV charging. Proper sizing depends on the intended use, expected solar surplus, and the facility's load profile.

Space and Infrastructure

While batteries don't require much space compared to the array, they must be safely housed in ground-mounted enclosures, often near the main electrical panel. These units should be protected with bollards or fencing and may require integrated climate control to maintain battery health during Michigan's winter. Carport canopies typically do not support the weight of batteries, so ground-level installation is standard.

Safety and Permitting

BESS installations must follow electrical safety standards (e.g., NEC Article 706) and fire codes. Large lithium-ion systems may require review by fire officials for clearance, fire suppression, and emergency access. Permits may include both electrical and structural approvals. Early consultation with local authorities is advised, and proper signage and emergency protocols should be implemented.

Economic Considerations

This section discusses the typical costs and financial considerations associated with installing and maintaining solar carports, including upfront installation costs, breakdowns of key components, and ongoing operations and maintenance (O&M) expenses. To help readers explore potential returns, a sample ROI estimation tool is provided (see the accompanying Sheet, **Appendix 3**. Users can adjust inputs such as installation cost, system size, electricity rates, and tax incentives in the sheet to model site-specific scenarios and estimate payback periods.

Step 1: Upfront Costs and Ongoing Expenses

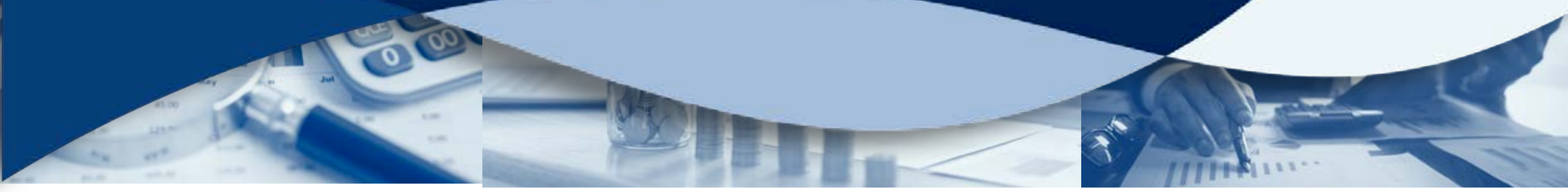
Installing a solar carport involves significant upfront costs, which are usually higher than a standard rooftop or a mounted solar system due to the need for a dedicated support structure. [30] In the U.S., the prices of solar carport installations vary; they typically range from $3.75 to $4.50 per watt for smaller systems (e.g., a 5 kW carport might cost approximately $18,000–$22,000 before incentives). Larger commercial-scale carports can have a higher upfront cost, but generally come down to roughly $2.75 – $3.50 per watt in installation costs. [31] These numbers consider several factors such as:

Components Cost Breakdown:

Key cost components include the photovoltaic panels and inverters, the carport canopy structure (often a major cost driver), foundation or mounting hardware, and electrical infrastructure (wiring, conduit, trenching, etc.). [32] Suppose the project integrates another add-on infrastructure, such as battery storage or EV charging stations. In that case, you should consider that these add-ons can enhance the carport's functionality but will significantly increase the upfront cost.

Operations & Maintenance (O&M):

Ongoing costs for solar carports are relatively cheaper compared to the capital expense. Solar PV systems generally require periodic panel cleaning, equipment inspections, and maintenance of inverters and electrical components. A rule of thumb is on the order of $15–$30 per kW per year in O&M costs for utility-scale systems, [33] though this can vary for smaller-scale systems. For example, one feasibility study of a ~500 kW solar carport + storage project estimated first-year O&M costs around $8,300 (on a $1.63 million system), which is roughly 0.5% of the initial investment.[34] O&M may rise slightly over time (the cited study assumed a 2% annual escalator on O&M) as equipment ages. Overall, expenses for cleaning, preventive maintenance, and occasional repairs are minor compared to the energy savings generated. However, if we add an add-on infrastructure such as battery storage, there could be additional maintenance or component replacement costs to consider.



Step 2: Ownership and Financing Models

The financing and ownership of a solar carport project have a significant impact on its economic outcome. Three typical models are usually used, and each of those models has trade-offs in terms of upfront cost, incentives, and long-term returns. [35] Those models are as follows:

Direct Ownership (Self-Finance)

The city, private sector, community, or individual directly purchases and owns the solar carport.

Advantages: The project owner receives the full benefit of all energy savings and any associated incentives. Over the system's lifetime, this typically results in the greatest net savings, as there's no third-party profit margin. Several tax credits are available for the private sector and individuals interested in being project owners, including the 30% Investment Tax Credit (ITC).

Trade-offs: For municipal entities and other nonprofits, the lack of tax incentives means that they cannot utilize federal tax credits. Therefore, this would make the return on Investment (ROI) for these entities significantly lower unless grant funding and other support were available. Additionally, the project owners also bear the performance risk and O&M responsibilities directly, so they must budget for long-term maintenance. [36]

Power Purchase Agreements (PPAs)

Under a PPA, a third-party solar developer finances, installs, and owns the carport system on municipal property, and the municipality agrees to buy the electricity generated at a set price per kWh over a long term (often 20–25 years). [37]

Advantages: This model has lower upfront costs for the user and shifts the responsibility of installation and maintenance to the developer. The PPA rate is typically lower than the utility's retail rate, providing immediate savings on energy bills. Most importantly, in the case of a municipal project, owners or NGOs that are not eligible for ITC can have the third-party owner capture the federal ITC and depreciation benefits, thereby offsetting those savings through a cheaper energy price.

Trade-offs: The total savings are split between the developer and the host, and the host is committed to maintaining purchasing power for the duration of the contract.

Lease or Other Third-Party Ownership

Similar to a PPA, a lease involves a third party owning the system, but the user might pay a fixed lease payment instead of per-kWh charges. [38]

Advantages: Third-party ownership models, such as leases or performance contracts, allow users to benefit from solar energy with little or no upfront investment. These models enable private partners to claim federal tax incentives, which reduces total system cost, and often include maintenance and performance guarantees, lowering operational burdens.

Trade-offs: Users may experience smaller long-term savings compared to direct ownership. They also have less control over system specifications, upgrades, or integration with other infrastructure. Legal complexities, like Michigan's rules on long-term contracts and utility regulations, must be carefully addressed to ensure compliance.

Step 3: Levelized Cost of Energy (LCOE) and ROI

Levelized Cost of Energy (LCOE)

is a metric that spreads a project's total costs over its lifetime of energy production, resulting in an effective cost per kilowatt-hour (kWh) generated. This is useful for comparing the cost of solar energy to buying power from the grid. [39] For Michigan solar carports, the LCOE will depend on installation cost, sunlight available, operational costs, and any incentives. Because Michigan has somewhat less solar irradiation and more snow losses in winter compared to sunnier states, the LCOE of a carport here will generally be higher than a project in the Southwest. In practical terms, many solar carport installations in the Midwest see LCOEs on the order of $0.08 to $0.15 per kWh. [40] One study modeling Walmart parking lot canopies found that in a low-cost scenario (~$1.25/W install), a region like Michigan would require a power price around $0.10 per kWh (with modest escalation) to break even. [41]

Return on Investment (ROI):

tells you how much value a project delivers compared to what it costs. For solar carports, this calculation can be performed in several ways. Some people use a simple payback method, such as dividing annual energy savings by the upfront cost, while others prefer a more detailed internal rate of return (IRR), which looks at performance over the system's whole life. [42] For example, if a system pays itself off in 10 years and lasts 25 years, you essentially get 15 years of "free" power, equivalent to a 150% return, not counting inflation or discounting.

In practical terms, people typically consider yearly returns (ROI or IRR) to determine if a solar project is a good investment compared to other options, such as bonds. Many government-backed solar projects aim for returns between 8% and 12% per year. One example, a solar carport combined with battery storage, showed a total return of 11.8% and an annual return of approximately 15.4% over a 20-year period. That was possible because of tax credits, rebates, and savings on electricity bills. Even in a cloudy state like Michigan, a well-designed solar carport can still achieve similar returns, mainly if it utilizes tax benefits or is constructed by a third-party company.

Environmental Considerations

Step 1: Carbon Offset and Environmental Impact

Beyond the economic and operational benefits, solar carports deliver measurable environmental impacts by offsetting greenhouse gas (GHG) emissions from grid-based electricity use. Estimating these benefits is a crucial component of the planning process, as it informs funding applications, public engagement, and broader sustainability strategies. To quantify environmental value, readers should:

- Estimate Annual Energy Generation (kWh) using tools like those referenced in **Appendix 2.**
- Apply Regional Emission Factors (kg of CO_2 per kWh) based on local grid data to calculate total avoided emissions.
- Translate Avoided Emissions into Equivalents (e.g., vehicles removed, homes powered, coal displaced) using resources such as the EPA Greenhouse Gas Equivalencies Calculator referenced in **Appendix 2.**

Presenting impacts in these terms enables municipalities to convey the broader climate value of solar carports in a format that stakeholders and the general public can easily understand and comprehend. While exact figures will vary by system size, location, and energy offset, including projected GHG reductions and equivalency metrics in project documentation is recommended as a best practice.

Appendix 1

Solar Incentives and Financing Resources (Michigan + Federal)

This section outlines federal and Michigan-specific programs, tax credits, and financing options that can help reduce upfront costs and improvethe financial feasibility of solar carport projects.

Category	Policy / Program	Description	Link
Federal	**Residential Clean Energy Credit (formerly Federal Investment Tax Credit)**	Provides a 30% tax credit on the total cost of a solar PV system, including equipment, labor, permitting, and sales tax. This incentive ends on **December 31, 2025** (per legislation signed July 4, 2025). Consult a tax professional for individual cases.	https://www.irs.gov/credits-deductions/residential-clean-energy-credit
State (Michigan)	**Solar for Savings: MI Solar for All Pilot Projects**	Pilot programs offering solar access and potential cost savings for Michigan households, particularly those with limited income or access to traditional solar financing.	https://www.michigan.gov/egle/about/organization/climate-and-energy/mi-healthy-climate-challenge/solar-for-savings
State + Federal	**DSIRE (Database of State Incentives for Renewables & Efficiency)**	Comprehensive database of state and federal incentives, tax credits, grants, and financing programs for renewable energy projects across the U.S.	https://www.dsireusa.org/
State (Michigan)	**Michigan Saves**	Michigan's green bank, offering financing and loans for renewable energy and energy efficiency projects (residential and commercial).	https://michigansaves.org/
Federal	**U.S. DOE Loan Programs Office (LPO)**	Provides loan guarantees and funding for large-scale renewable energy projects, including municipal or commercial solar carport projects.	https://www.energy.gov/lpo

Solar Project Planning Tools and Resources

This appendix provides a curated list of tools, software, and financing resources to support the feasibility studies and development of solar carports. These resources include

Table 1. List of Solar Irradiance Tools and Databases

Name	Description	Link
NREL National Solar Radiation Database (NSRDB)	Historical solar radiation and meteorological data for the U.S.	https://nsrdb.nrel.gov/
PVGIS (Photovoltaic Geographical Information System)	Solar radiation data and PV performance for global locations	https://ec.europa.eu/jrc/en/pvgis
Solargis	High-resolution global solar resource data and maps (commercial)	https://solargis.com/maps-and-gis-data/download/
DSIRE (Database of State Incentives for Renewables & Efficiency)	Comprehensive database of incentives, tax credits, and grants by state for renewable energy projects.	https://www.dsireusa.org/
Michigan Saves	Financing programs specifically for renewable energy and energy efficiency projects in Michigan.	https://michigansaves.org/
U.S. DOE Loan Programs Office	Federal loan guarantees and funding for large-scale clean energy projects.	https://www.energy.gov/lpo

Table 2. List of Shading Analysis Tools

Name	Description	Link
Aurora Solar	Cloud-based design tool with 3D shading analysis	https://www.aurorasolar.com/
Helioscope	Combines PV system design with real-world shading simulation	https://www.helioscope.com/
SketchUp + Skelion Plugin	3D modeling and shading assessment with real location sun data	SketchUp / Skelion
Solmetric SunEye	Handheld device for site-specific shading analysis (hardware)	SunEye

Table 3. List of Simple Solar Estimation Calculation Tools

Name	Description	Link
PVWatts Calculator (NREL)	User-friendly tool for estimating solar production	https://pvwatts.nrel.gov/
EnergySage Solar Calculator	Basic solar and financial estimator	https://www.energysage.com/solar/calculator/

Table 4. List of solar estimation software

Software	Description	Link
NREL SAM (System Advisor Model)	Comprehensive performance and financial modeling tool	https://sam.nrel.gov/
PVsyst	Detailed energy yield simulations with loss breakdown	https://www.pvsyst.com/
HOMER Grid	For hybrid system and microgrid simulations including storage	https://www.homerenergy.com/products/grid/index.html

Table 5. Environmental Impact and Carbon Offset Tools

Tool	Description	Link
EPA Greenhouse Gas Equivalencies Calculator	Converts annual energy generation or avoided emissions (in kWh or metric tons of CO_2) into relatable metrics, such as the number of vehicles removed, homes powered, or acres of forest preserved. Helpful in reporting and outreach.	https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
GHG Protocol Emissions Factors Hub	Provides standardized emission factors (in kg CO_2 per kWh) for regional grids, which can be used to estimate the avoided emissions from solar generation.	https://ghgprotocol.org/
CARB Low Carbon Fuel Standard Reporting Tools	Offers emission conversion factors and calculators, primarily for transportation and fuel-related offsets but adaptable for energy projects.	https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

Appendix 3

Simple ROI Estimation Formula

This appendix provides an editable Excel-based tool for estimating the return on investment (ROI) and payback period of solar carport projects. Users can adjust system size, costs, incentives, and local utility rates to model project-specific scenarios. The tool can be accessed through this link: ***[Link]***.

Glossary

- **W (Watt) –** A basic unit of power. 1,000 watts equals 1 kilowatt (kW).
- **kW (Kilowatt) –** A measure of power output, often used to describe the size of a solar system.
- **MW (Megawatt) –** A unit of power equal to 1,000 kilowatts.
- **kWh (Kilowatt-hour) –** A measure of energy use or production. One kWh equals using 1,000 watts for one hour.
- **PV (Photovoltaic) –** The technology in solar panels that converts sunlight directly into electricity.
- **AC (Alternating Current) –** The type of electricity used in homes and on the grid. Solar panels produce DC, which is converted to AC by an inverter.
- **DC (Direct Current) –** The type of electricity generated by solar panels before it is converted to AC.
- **Tilt Angle –** The angle at which solar panels are mounted, optimized for sun exposure and snow shedding in Michigan (often 20–40°).
- **Degradation Rate –** The annual percentage decline in solar panel efficiency (commonly ~0.5% per year).
- **O&M (Operations & Maintenance) –** Annual costs for cleaning, inspections, and minor repairs to keep the solar carport operating.
- **BESS (Battery Energy Storage System) –** A system that stores excess solar energy for later use, such as during peak demand or outages.
- **EV (Electric Vehicle) –** A vehicle powered by electricity, often charged using solar carport-integrated chargers.
- **DSIRE (Database of State Incentives for Renewables & Efficiency) –** A national database listing renewable energy tax credits, grants, and other incentives.
- **NSRDB (National Solar Radiation Database) –** A U.S. database of solar radiation and weather data, used for estimating solar energy production.
- **IBC (International Building Code) –** Standardized construction codes covering structural safety, including snow and wind loads.
- **IFC (International Fire Code) –** Safety standards covering fire lane access and clearance, relevant to solar carport designs.
- **NEC (National Electrical Code) –** Standards for safe electrical system installations, including PV systems.
- **LCOE (Levelized Cost of Energy) –** The average cost to generate one kilowatt-hour of electricity over a system's lifetime, factoring in all costs.
- **ROI (Return on Investment) –** A measure of how quickly or profitably the solar system pays back its installation cost.
- **PPA (Power Purchase Agreement) –** A financing model where a third party owns and operates the solar system, and the site host purchases the electricity it generates at a set rate.

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