DISCLAIMER

ORNL/TM-2025/4141

Return on Investment (ROI) Calculations for Residential Rooftop Solar Energy: A User Guide

Dr. Archana Ghodeswar
R&D Associate, Certified Energy Manager
Integrated Building Deployment and Analysis Group
Energy Science and Technology Directorate
Oak Ridge National Laboratory, Tennessee

Dr. Drazenka Svedruzic
Senior Scientist- Biosciences Center
Energy to Communities (E2C) Technical Assistance Coordinator
National Renewable Energy Laboratory (NREL)

February 2025

ORNL/TM-2025/4141

DOE E2C Program
Expert Match Program

ROI Calculations for Residential Rooftop Solar Energy: A User Guide

Technical Assistance Document

Dr. Archana Ghodeswar
R&D Associate
Integrated Building Deployment and Analysis Group
Energy Science and Technology Directorate
Oak Ridge National Laboratory, Tennessee

Dr. Drazenka Svedruzic
Senior Scientist- Biosciences Center
E2C Technical Assistance Coordinator
NREL

February 2025

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

ABBREVIATIONS AND ACRONYMS

E2C	Energy to Communities
DOE	The Department of Energy
EPA	Environmental Protection Fund
HVAC	Heating Ventilation and Air Conditioning
kWh	Kilowatt hour
kW_p	Kilowatt peak
NPV	Net Present Value
ROI	Return On Investment
PV	Photovoltaic
TA	Technical Assistance

Objective

This scope outlines specific areas of technical assistance (TA) support to be provided to "Clean Energy Districts of Iowa (CEDI)", Tama County, Montour, Iowa, under the DOE E2C Expert Match Program.

Background

Tama County, including the small community of Montour, Iowa, with fewer than 10,000 residents, faces notable challenges in energy resource efficiency, particularly in relation to aging infrastructure and energy justice. Montour is mostly a residential and farming community, with many older homes in need of rehabilitation. Energy efficiency upgrades are critical to reduce energy waste and lower costs. However, limited financial resources and access to modern technology make it difficult for low- and moderate-income households to implement necessary improvements.

Infrastructure in the area, particularly in residential and public buildings, requires modernization to support renewable energy technologies like solar panels and to accommodate energy-efficient systems, such as improved insulation and HVAC systems that enhance Indoor Air Quality. One of the first steps to address these issues could be an educational campaign and micro-learning initiatives, which would empower homeowners and businesses to adopt energy-saving practices. Educational programs focused on energy efficiency and Return on Investment (ROI) will aim to make integrated variety energy solutions more accessible. These initiatives will help provide a more accurate estimated ROI that considers potential benefits and risks, offering a true picture of the future potential of residential rooftop solar systems. They will also enhance energy security and present a clearer view of affordability. By reducing costs, these programs ensure that all residents, especially those in rural communities, can benefit from the technical aspects of resource energy efficiency practices and improved air quality.

DOE E2C Program

The E2C program is a DOE-funded effort designed to provide technical support to communities transitioning to alternative energy economies. E2C includes the "Expert Match" TA offering, through which DOE national laboratories and other partners provide tailored technical support to communities in response to submitted requests. A typical request will include 40–60 hours of technical support on a topic where expert assistance is critical to the community making an informed energy decision.

Montour's request was selected because it presents a clear case for TA due to energy challenges, aging infrastructure, and alignment with DOE's goal of advancing reliable energy solutions in rural communities. Specific criteria include:

- *Rural Community*: Montour, as part of Tama County, includes a significant percentage of rural communities. These populations often face higher energy burdens and have fewer resources to invest in energy efficiency and renewable energy technologies. E2C's mission to provide alternative energy access that aligns with the needs of communities like Montour.
- *Aging Infrastructure and Energy Efficiency Needs*: Many homes and buildings in Montour are older and require rehabilitation and upgrades to meet modern energy efficiency standards. Addressing these infrastructure issues would reduce energy consumption, improve indoor air quality, and lower energy costs, directly supporting the goals of the E2C program.
- *Community Capacity and Engagement*: Although Montour has moderate in-house capacity dedicated to energy efficiency, the technical expertise and resources provided by the E2C program would greatly enhance local efforts. The program can help build community knowledge through educational initiatives like micro-learning, enabling the community to make informed decisions about energy savings.
- *Scalable Impact:* By assisting a small, Montour community, the E2C program can create a model for how similar rural communities can shift to alternative energy which is more localized. Success in Montour could provide valuable lessons and a scalable blueprint for other communities facing similar challenges across the United States.

Proposed Work

The goal of this project is to provide targeted TA that offers homeowners and local businesses with knowledge about energy efficiency options and how to effectively implement them.

Given that the TA offered through the E2C program is limited to 40–60 hours and provides light-touch assistance, this project will focus specifically on the ROI of residential rooftop solar system as a key area, providing a blueprint for future buildings design related education efforts within the community.

Montour community members are interested in understanding how ROI is calculated and how decisions are made based on it. Currently, private solar panel providers offer various financial projections, but these often appear inconsistent and may not be based on the most accurate or up-to-date data. Additionally, these providers collect contact information and follow up with residents, which some homeowners in the community may find inconvenient or unexpected. There is no user-friendly online resource specifically designed to calculate ROI for rooftop solar installations in Tama County. The community would benefit from a more accurate estimated ROI that considers both potential benefits and risks, providing a clearer understanding of the true future potential of residential rooftop solar systems.

Based on a request from Tama County and after exploring various TA options for alternative energy, the E2C program has developed an Excel-based dashboard to provide a user-friendly ROI calculator for rooftop solar systems. This document includes basic information on ROI and a user guide to help users navigate the Excel-based calculator effectively.

Return on Investment Basics

Definition, formula and examples:

ROI is a financial metric used to evaluate the efficiency or profitability of an investment relative to its costs. It is calculated using the formula:

$$ROI = \frac{\text{Net Gain from Investment}}{\text{Cost of Investment}} \times 100$$

This metric is critical in decision-making processes as it allows communities, organizations, and stakeholders to assess the value gained from specific initiatives, sector. ROI measures the cost-effectiveness of the investment efforts and is generally described as the total return relative to the initial costs, considering the time value of money across energy efficiency programs. Understanding ROI enables communities to estimate both immediate financial benefits, like cost savings on energy and long-term advantages, such as improved health outcomes and energy security. In the context of the E2C program, ROI provides insight into the economic viability of infrastructure upgrades, energy efficiency improvements, and educational initiatives designed to lower energy consumption and promote resource efficiency practices.

As a simple example, consider a small community investing $50,000 in solar energy systems for public buildings, with the expectation of reducing annual energy costs by $10,000.

Here, the ROI calculation would be:

$$ROI = \frac{\text{Net Gain from Investment}}{\text{Cost of Investment}} \times 100$$

$$ROI = \frac{10000}{50000} \times 100 = 20\%$$

This 20% ROI means that, over five years, the community will effectively recoup the cost of its initial investment in energy savings alone. Additionally, there are likely nonfinancial benefits, such as reduced carbon emissions and enhanced community energy security, further amplifying the value of this investment beyond the financial returns.

The above example is a simplified illustration to help understand the basics of ROI. However, the ROI for solar photovoltaic (PV) should ideally account for environmental factors affecting optimal energy generation, the discount rate, annual electricity rate increases, system efficiency, and variations in solar radiation throughout the year when calculating savings. Investments should incorporate rebates, tax credits, loan interest rates, and annual maintenance costs. Additionally, future savings and expenses should be adjusted to their present value using the discount rate.

By understanding and actively monitoring ROI, communities can make informed, data-driven decisions that support resource efficiency growth and energy security.

What ROI does not tell?

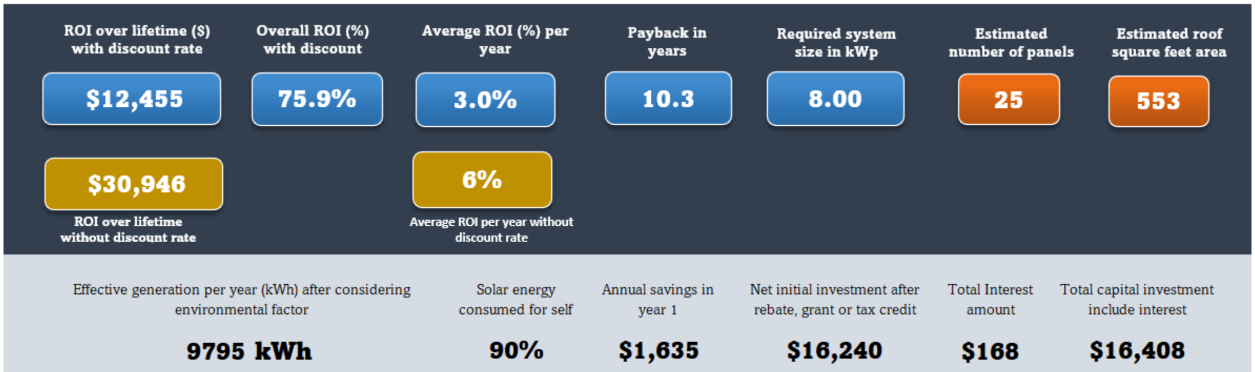
ROI considers the monetary value of the gain or benefit from the investment. It does not reflect the indirect benefits of the investment, which may not be always quantifiable. For example, increase in the system's reliability and adaptive capacity due to modern energy technology is not of the same value to all, and investment in these energy technologies for community energy security may have an ROI less than the perceived ROI (that includes financial gain, energy security, and other co-benefits). Also, ROI may not always consider the time value of money and the opportunity cost. Therefore, measuring the cost effectiveness of modern energy technology investment by ROI should be cautiously apprehended.

Key Benefits of a good ROI estimate:

The key indicator of having a good ROI is reduction in energy bills, especially critical for low energy-affordability households. Energy-efficient upgrades can enhance building value. The high ROI for solar PV system strengthens local energy capacity and energy independence, benefiting all community members.

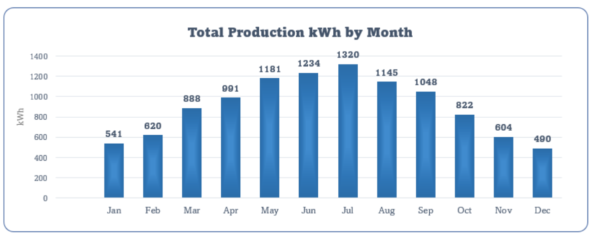
ROI Calculator for Residential Rooftop Solar Panels

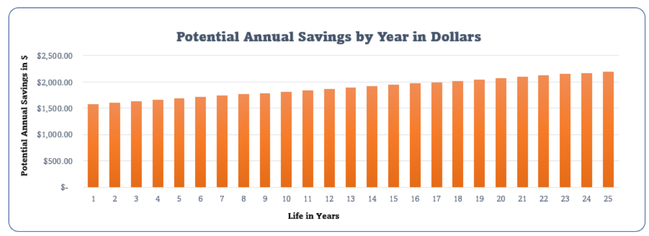
This section provides guidance to use ROI Calculator for residential rooftop solar panels. It explains the inputs required, outputs generated, and the underlying assumptions to guide users in evaluating the financial and environmental benefits of solar installations. The output part of the dashboard is displayed as shown below.



The ROI Calculator is designed to:

1. Help users calculate the ROI and payback period for solar panel installations.
2. Display graphs of estimated potential monthly electricity generation (in kWh) and cumulative savings over the system's lifetime.





3. Provide two types of ROI calculations:
   - **Discounted ROI**: Incorporates the time value of money.
   - **Non-Discounted ROI**: Does not account for discounting.
4. Estimate the number of panels required and approximate roof space needed for the selected system size.

User Selection and Inputs Required:

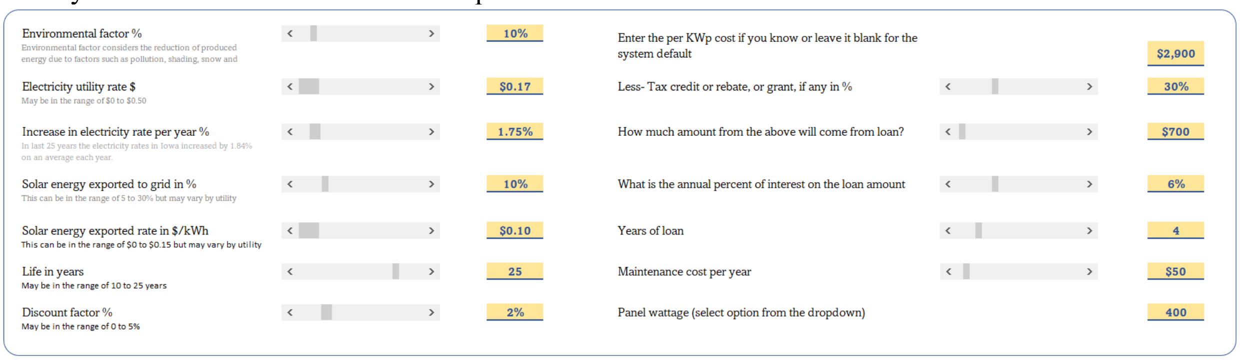
Users can choose to select a primary input by hitting appropriate radio button and input the numerical information as seen in the screenshot of the part of the dashboard in the above picture. The four input options are:

- System size in kW_p (input required in the range of 1–20 kW) -OR-
- Average monthly electricity consumption in kWh (input required in the range of 50–1500 kW) -OR-

- Square feet area of the house (input required in the range of 500–3000 square feet) -OR-
- Average monthly electricity bill in dollars (input required in the range of $20–$1000)

If a user chooses to enter their average monthly electricity consumption, home size in square feet, or average electricity bill instead of the system size in kWp, the tool will automatically estimate the appropriate system size. The accepted ranges for these inputs are 50–1,500 kWh for electricity consumption, 500–3,000 square feet for home size, and $20–$1,000 for the monthly electricity bill. The system size estimation is based on predefined assumptions related to energy needs and efficiency factors. Once the system size is calculated, all subsequent financial and performance calculations follow the same process as when the system size is directly entered in kWp.

Additional Required Inputs: Additional inputs can be selected using the scroll bar or entering the values in the yellow color cells as shown in the picture below.



Users need to provide the following details:

1. Environmental factor: Environmental factors consider the reduction of produced energy due to factors such as pollution, shading, snow, and other. The user can select from 0% in ideal case up to the percent of physical barriers she thinks can impair the solar generation. Practically, the environmental factor is in the range of 5–15%.

2. Electricity rate: This is the retail rate of electricity from the local utility in dollars. In general, for Iowa, it is in the range of $0.15–0.20.

3. Increase in electricity rate per year: The electricity rate typically increases each year. In last year the electricity rate in Iowa have seen an annual increase by 1.84% on an average.[1] The user can enter the rate of increase in the electricity in the range 1–5%.

4. Solar energy exported to the grid: Some utilities permit residential consumers to export excess rooftop solar power to the grid. These consumers, referred to as prosumers, both consume and supply electricity. The quantity of electricity exported, and the timing of such exports are regulated by state policies and utility-specific terms and conditions. Depending on the contractual agreement, utilities may offer bill credits or adjust electricity consumption charges for prosumers at the end of the billing cycle, either monthly or annually. Users can specify the percentage of solar energy they are permitted to export to the grid. Generally, utilities impose export limits ranging from 10% to 20%, though these limits may vary based on utility regulations and policy changes over time.

[1] Environmental Protection Agency (EPA) website https://www.eia.gov/opendata/browser/electricity and https://www.solarreviews.com/blog/average-electricity-cost-increase-per-year

5. Solar Energy Export Rate: The utility pays the prosumers for the electricity exported to the grid. This can be in the form of credit in the bill or consumption, as mentioned earlier. The rate of electricity for export is usually little less than the electricity rate for consumption. It can range from $0.05-0.15 per kWh. More information can be found on net metering policy can be found in the DSIRE database[2].

6. System Life in Years: The lifespan of the solar system determines the duration over which savings are considered in ROI calculations. Users should enter the system's lifespan within the range of 15 to 25 years. The tool will automatically account for discounted and cumulative savings based on the specified system life.

7. Discount Factor: The discount factor accounts for the time value of money by adjusting future savings to their present value. Typically ranging from 1% to 5%, a higher discount rate results in a lower ROI, as future savings are devalued more significantly. Users should select an appropriate discount rate based on their financial assumptions and investment outlook.

8. Solar PV System Cost: The solar PV system cost encompasses the total expenses associated with solar panel installation, including procurement, logistics, and installation. The tool allows users to enter the cost per 1 kW of the solar system. If the user is unsure of this value, the field can be left blank, and the tool will automatically apply the default cost of $2,900 per 1 kW for ROI calculations.

9. Tax Credit, Rebate, or Grant: Tax credits, rebates, or grants may be available through local government programs, utilities, or nonprofit organizations to offset a portion of the solar system installation costs. Users should enter the percentage of the total cost covered by such incentives. The tool will automatically deduct this percentage from the total solar system cost, reducing the net investment required. More details can be found in the DSIRE database.[3]

10. Loan Amount: Users should enter the loan amount in dollars if they intend to finance the solar system through a loan from a bank or another lender. If the entire system cost is being financed through a loan, the user should enter the net cost of the solar system after applying tax credits, rebates, or grants from the previous field.

11. Annual Interest Rate on Loan: The user should enter the annual percent of interest. This can be in the range of 0–15%.

12. Loan duration: Enter the number of years for which the loan is taken. This duration will be used to calculate the total interest amount, which will be added to the net cost of the solar system based on the formula for simple interest.

13. Maintenance Cost: Users should enter the estimated annual maintenance cost of the solar system. This cost typically ranges from $10 to $50 per kW per year on average over the system's lifetime. The net present value (NPV) of these costs, discounted using the specified discount rate, will be included in the total cost calculations.

---

[2] NC energy technology center maintains policy database which is available on https://programs.dsireusa.org/system/program/detail/488/net-metering
Accessed in December 2024.

[3] https://programs.dsireusa.org/system/program/detail/1235/residential-renewable-energy-tax-credit and https://www.energy.gov/eere/solar/homeowners-guide-federal-tax-credit-solar-photovoltaics accessed in December 2024

Calculations

1) Annual savings: The tool calculates annual savings based on the installed system size, solar radiation data provided by NREL's PVWatts calculator, inverter efficiency (default value of 96%), DC to AC size ratio (default value of 1.04), and system losses (default value of 14%).[4] The electricity generated by the system is consumed by the residence, with any excess exported to the grid. The annual savings are determined using the following formula:

   Annual savings = (Units consumed × Electricity bill rate in $) – (Units exported × Electricity export rate)
   For example, if the solar system produces 3,000 units, with the resident consuming 2,400 units at a rate of $0.17 per unit and exporting 600 units to the grid at a rate of $0.10 per unit, the annual savings would be:
   Annual savings = (2400 × 0.17) + (600 × 0.10) = $468.

2) NPV: The NPV of annual savings is calculated using the discount factor over the system's lifetime to account for the time value of money. This provides a realistic measure of financial performance.

3) Panel Wattage: Solar panels are available in various capacities, typically ranging from 200 watts to 475 watts. The wattage of the selected panels determines the estimated number of panels required and the total roof area needed for the installation of the chosen solar system size. The number of panels required is calculated using the formula:

Number of panels = System size in kW/Panel wattage
The estimated square footage required on the roof for the panels is determined based on the assumption that a 400-watt panel occupies approximately 17.7 square feet.[5]

Assumptions

The following assumptions have been considered to ensure realistic estimations in the ROI calculator for residential rooftop solar panels.

1. The average solar radiation data in kWh/m²/day for each month is obtained from NREL's PVWatts calculator, which relies on solar resource data from the NREL National Solar Radiation Database. The estimated annual electricity generation is based on solar radiation levels for Marshalltown, Iowa (ZIP code 50158). According to PVWatts, the annual average solar radiation in Marshalltown is 4.71 kWh/m²/day, which represents the median radiation value for all 18 ZIP codes in Tama County. The estimated annual solar output for a 1 kWp system in Marshalltown is 1,360 kWh, which also corresponds to the median system output for the county. Solar radiation and system output in other towns within Tama County fluctuate by approximately ±2% of Marshalltown's values, potentially resulting in a ±10-15% change in annual electricity generation and savings.

[4] Solar irradiation is referred from NREL's PVWatts calculator available at https://pvwatts.nrel.gov/pvwatts.php. This calculator can be used to estimate the electricity units generated by solar PV. It also provides the solar radiation by month by zip code. The solar radiation in kWh/m^2/day was referred from this PVWatts calculator for 1kW solar PV system for zip code 50158 and used in the current ROI calculator to calculate annual electricity units generated. The calculator is available at https://pvwatts.nrel.gov/pvwatts.php

[5] Calculation reference- https://www.solarreviews.com/blog/how-many-solar-panels-do-i-need-to-run-my-house

The annual solar generation would be approximately the same for the locations where the solar radiation is in the range of +2% of 4.71 kW/m2/day. The following map can be referred for referring the solar radiation.

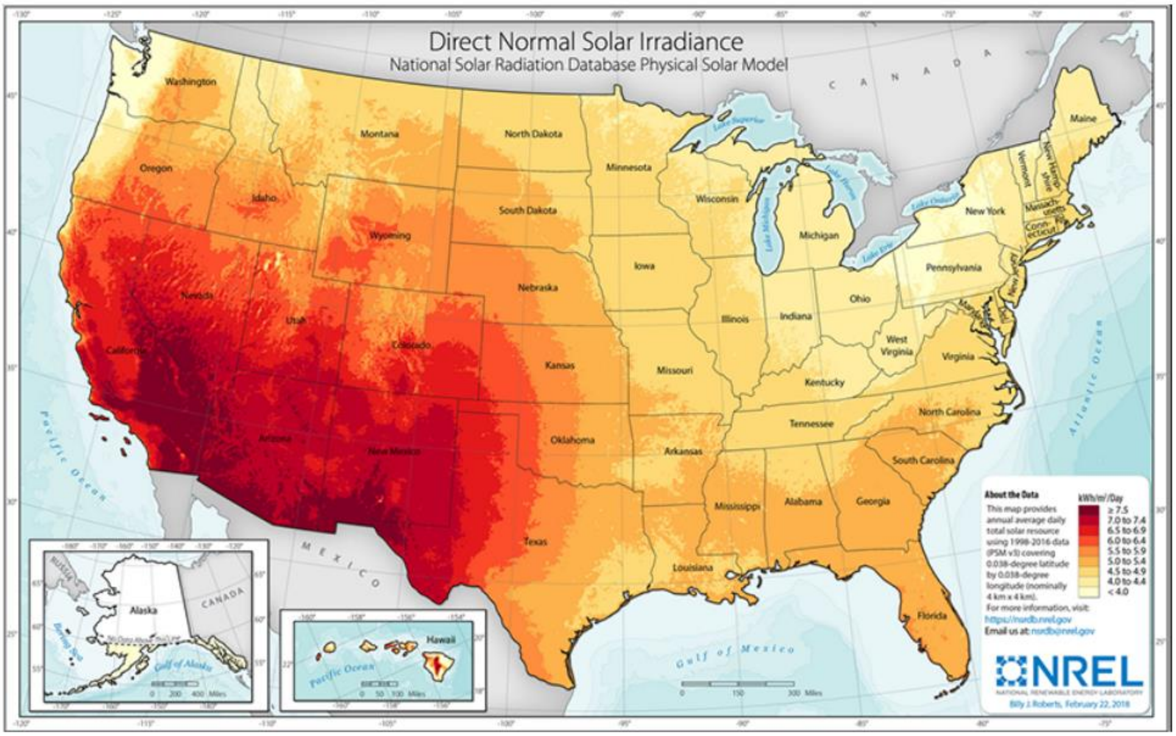


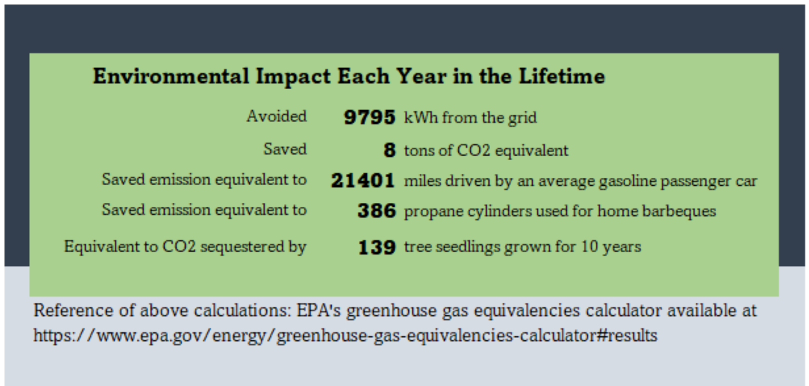
Figure 1. Map showing solar radiation in the US. Solar radiation increases from areas having lighter color towards darker colors. The intensity of solar radiation in a particular area impacts the ROI positively. Source reference: National Renewable Energy Laboratory, U.S. Department of Energy. The above map is accessible at https://www.eia.gov/energyexplained/solar/where-solar-is-found.php

However, ROI values in both absolute terms and percentages are more sensitive to variations in the discount rate.

2. The system assumes the use of standard crystalline silicon solar panels with an approximate nominal efficiency of 19%. These panels are made of glass with an antireflective coating and possess a temperature coefficient of power of -0.37%/°C.
3. The ratio of the array's DC-rated capacity to the inverter's AC-rated capacity is assumed to be 1.04. If this ratio is higher, the calculated electricity generation will be lower, and vice versa.
4. The estimated annual generation remains relatively stable for locations where solar radiation varies within ±2% of 4.71 kWh/m²/day.
5. The solar array is assumed to be fixed and mounted to a roof, with a default panel tilt angle of 20° and an azimuth orientation of 180° (south-facing).
6. System losses- which account for soiling, shading, wiring, mismatch, light-induced degradation, and connection inefficiencies - are estimated at 14%.

7. The assumed standard inverter efficiency is 96%.

8. The approximate environmental impact of installing a rooftop solar system is assessed using the EPA's Greenhouse Gas Equivalencies Calculator.[6] The tool estimates avoided grid electricity usage in kWh and the equivalent reduction in CO_2 emissions, helping users understand the environmental footprint of their roof-top solar system installation. The picture below shows the display of approximate environmental impact in an example system size of 8 kW.



9. ROI calculations **exclude** battery storage related costs. The model does not estimate battery costs, savings, or operational impacts. Additionally, it **does not** account for potential inverter replacement during the lifetime of the solar system. The user may consider adding the maintenance cost per year for such allied replacement costs along the way.

[6] EPA's online calculator available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results updated in November 2024.