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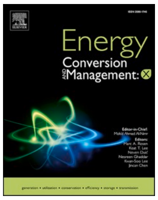

Comparison of mono and bifacial modules for building integration and electric vehicle charging: A case study in Sweden

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ABSTRACT

Future energy systems have a major difficulty in ensuring a reliable supply of electricity without affecting the environment, and numerous innovative renewables-based solutions are being introduced to meet this issue. This paper proposes a building photovoltaic (PV) system design for residential and electric vehicle (EV) charging demand and evaluates the techno-economic and environmental performance of the system in Orebro, Sweden, as it aims to become net zero carbon economy by 2045. Literature review shows that, although many studies exist, most of them did not fully consider the techno-economic and environmental aspects of PV systems for residential and EV charging loads in the chosen location. Two different PV technologies monofacial and bifacial monocrystalline panel in three different roof slopes 15°,30° and 45° has been analyzed to find the optimized system that can meet a typical house's annual energy demand. Economic indicators such as cumulative cash flow, levelized cost of electricity (LCOE), payback period and cost of EV charging have been evaluated for the PV system without discount and with discount which affects the system's profitability. PVSyst software was used to simulate the system for energy generation. Results have shown that the bifacial PV system performed better in energy generation, which is approximately 10% higher than the monofacial panel. However, in terms of economics, Case 6, a bifacial PV system with a roof angle of 45°, shows the lowest payback period of 7.3 years. In contrast, monofacial PV system with roof slope of 30° showed LCOE of 0.8988 Swedish Krona per kilowatt hour (SEK/kWh), EV charging cost of 0.1471 Swedish Krona per kilometer (SEK/km). Environmental parameters such as greenhouse gases (GHG) reduction have been analyzed. Results showed that GHG savings due to EV was higher than PV plant as Sweden's grid emission factor is very low due to less dependency on fossil fuels. The significance of this study will enable us to understand the performance of PV systems in Swedish aspect and methods can be extended to other countries for meeting location-specific energy demand.

1. Introduction

Global energy demand is soaring, placing pressure on major markets, driving prices to new highs, and pushing emissions from the energy sector to new highs. Energy is fundamental to modern life, and clean energy is critical to decarbonization; nevertheless, unless the industry undergoes faster structural reform, rising demand in the following years may increase market volatility and continuing high emissions[1]. One of the most challenging tasks that humanity has faced is the transition to a net-zero planet. It necessitates a radical revolution in creating, consuming, and traveling. The energy sector accounts for around three-quarters of greenhouse gas emissions and is critical to mitigating climate change's worst consequences [2]. Significant reductions in carbon emissions might be achieved by switching from coal, gas, and oil-fired electricity to renewable energy sources like wind and solar. More than 70 nations have established a net-zero emission target, accounting for around 76 percent of global emissions[2]. According to the UN, meeting the milestones outlined in the plan would allow the world to attain net-zero emissions by 2050. And, without comprehensive decarbonization of global energy systems, the Paris Agreement's objective of limiting global warming to 1.5°Celsius will swiftly "slip out of reach.". To reduce global emissions, United Nations (UN) SDG7 Global Roadmap details how the world may transition to sustainable energy by 2030 to achieve net zero greenhouse gas emissions by 2050 [3]. There are many causes for the switch, but the primary one is the strict decarbonization to

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Nomenclature

PV	Photovoltaics
EV	Electric vehicle
DHW	Domestic hot water
OPTA	Optimum tilt to maximize yearly yield
SEK	Swedish krona
TGC	Tradable green certificate
ROI	Return on investment
B_{EV}	EV battery capacity in kWh
R	Range of EV in km
D	Daily commute distance
E_{EV}	Daily kWh requirement
E_{H}	Daily residential load in kWh
E_{EV}	Daily EV charging load in kWh
E_{Total}	Daily total load in kWh
δ	Panel Degradation %
n	number of years
E_{n}	energy produced n^{th} year, kWh
E_{0}	energy produced in the first year, kWh
E_{Out}	Actual output of the system, kWh
E_{Full}	Full Capacity of system when work 24 h, kWh.
PR	Performance ratio
Y_{f}	System yield
Y_{r}	Reference yield
NPV	Net present value
PB	Payback period without discount in years
PD-D	Payback period for with discount in year
C_{inf}	Total cash inflows in Swedish krona
$C_{outflow}$	Total cash outflows in Swedish krona
NCF	Net Cash flow without discount in SEK
NCF-D	Net cash flow for PV system with discount in Swedish krona
LCOE	Levelized Cost of energy Swedish krona per kilowatt hour
PMWh	The constant lifetime remuneration to the supplier for electricity.
$(1+r)^{-t}$	The real discount rate corresponding to the Cost of capital.
$Capital_{t}$	Total capital construction costs in year t;
$O\&M_{t}$	Operation and maintenance costs in year t;
$Fuel_{t}$	Fuel costs in year t;
$Carbon_{t}$	Carbon costs in year t;
D_{t}	Decommissioning and waste management costs in year t.
GHG_{EV}	Emission reduction due to avoidance of gasoline.
$D_{lifetime}$	Total commute distance over lifetime in km.
GHG_{Total}	Total emission reduction by PV plant and transportation in $kgCO_2e$
EF_{Fuel}	Emission factor for gasoline $kgCO_2/km$
MWh	The amount of electricity produced annually in Mega Watt hours;
E_{L}	Total energy produced over the system's lifetime in Mega Watt hours
C_{EV}	Cost of EV charging SEK/km
F_{Grid}	Grid emission factor of power plant in $kgCO_2e/kWh$
GHG_{Energy}	Emission reduction by PV Plant
C_{Bill}	Annual savings on the System
C_{Res}	Annual residential electricity Bill
$C_{Transport}$	Annual savings on fuel
$C_{Grid\text{-}A}$	Revenue generated after energy sale to grid,
$E_{grid\text{-}Total}$	energy exported to grid over 25 years.
E_{Import}	Net energy imported over 25 years
C_{Import}	Cost of electricity for imported energy
C_{System}	Initial Cost of PV plant
$C_{Replacement}$	BOS replacement cost respective to PV system
$C_{Maintenance}$	Maintenance cost of system over lifetime

reduce carbon dioxide (CO_2) emissions and limit the rise in global temperatures below 1.5° C relative to pre-industrial levels[4].

1.1. Literature review

Sweden, ranked fourth in power and heat production, already produces 100% of its electricity from low-carbon sources. Due to government initiatives around electric vehicle charging legislation and low-carbon fuel standards, the nation is ranked second in transportation. Before its Net Zero objective of 2045, the country seeks to eliminate all fossil fuels from the transportation sector by 2030[5]. Fig. 1 below shows Sweden's energy mix, which shows that fossil fuel dependency is very low. However, the adoption of solar is still 1% which is very low[6].

In 2020, 2.9 TWh of electricity was consumed in the transportation industry, of which 2.4 TWh was used for rail travel and 0.5 TWh for road traffic. Due to a rising percentage of rechargeable cars in the fleet, energy usage in road traffic has grown dramatically in recent years and is predicted to continue to rise [6].

Within the next few decades, Sweden will undergo an energy transition, moving away from fossil fuels and toward renewable energy[8]. As a result of the climate action plan, Sweden's construction and energy sectors face significant problems. Whereas the construction sector is subject to a decarbonization strategy, the energy sector (electricity and heat) is expected to contribute to the goals by producing harmful carbon emissions [9]. The amount of purchased electricity used by public buildings should be 50% lower by 2050 than in 1995. The industry and construction sectors must meet specific intermediate targets since they comprise about 40% of the final energy consumption [10]. With 38.7%

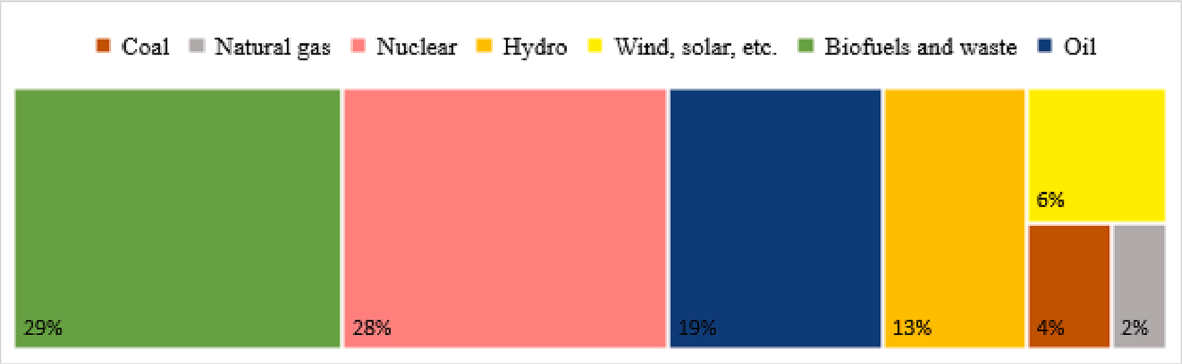


Fig. 1. Energy mix for Sweden [7].

of the total electricity generated from renewable energy sources, hydropower was the dominant source. Solar energy contributed 0.2% to electricity generation, while wind energy comprised 10.4%[11]. The installed capacity of solar systems in Sweden in 2019 was 698.05 MW or 68 Watts per resident. Finland and Norway, Sweden's neighbors in the Nordic region, have lower statistics than Sweden, with 39 and 17 W installed per inhabitant, respectively[12].

Around 300 kW of grid-connected PV systems were installed in Sweden in 2006, which might be considered the year when the industry took off. Before it, a small number of grid-connected systems were installed yearly. Most of the modest but steady off-grid business comprised the Swedish PV market until 2006, consisting of systems for vacation homes, boats, and trailers. Of the grid-connected PV capacity installed in 2020, 40.37 MW is estimated to be centralized PV parks and 358.10 MW distributed PV systems for primary self-consumption [13]. The number of grid-connected PV installations in Sweden is increasing rapidly, with an average growth rate of about 55% during the last four years[14]. Several obstacles exist to installing photovoltaic (PV) systems on the Swedish market. Low yearly irradiation in the country's northern areas, high seasonal changes in solar irradiation, and low energy costs all harm the viability of PV systems[15]. According to [16], solar energy is a complex subject for the general population, and awareness of the issue is low. It was found that peer effects to promote PV adoption occurred between people who already knew each other through direct interaction instead of being exposed to PV installations in the neighborhood [17].

Additionally, Sweden has been observed to take increasingly bold municipal actions to encourage and support the adoption of PV, whether through pilot projects or other means[18]. One example can be given based on the campaign mentioned above discussed by another is the example that Malmö municipality is setting by investing in the installation of PV on industrial buildings [19]. To promote the use of renewable energy on an urban scale and to guarantee financial feasibility, it is crucial to investigate and optimize PV in existing buildings [20].

A renewable electricity certificate, also known as a tradable green certificate (TGC), was first used in Sweden in 2003 and has since become the primary strategy for boosting renewable electricity production in that country[21]. Unlike many other European nations, Sweden has never implemented a feed-in-tariff program, generally the preferred and most successful strategy for adopting new technologies[22]. Alternatively, a PV-specific capital investment scheme was launched in 2005, which ignited the PV market. Sweden has variants of this regulation until the end of 2020[23]. A PV investor may receive government funding to pay 70% of the installation expenses when the capital investment incentive was first implemented in 2005. Since then, incremental reductions in the maximum coverage of the installation expenses have been made [24]. Smaller solar energy producers are eligible for a tax deduction of SEK 0.6 (about EUR 0.06) per kWh generated to encourage energy production from sustainable sources. The Swedish government offers businesses and ordinary citizens financial assistance for the costs associated with installing renewable energy sources. For private persons, the contribution can be up to 20%, while for businesses, it can be up to 30%[25]. In the second half of 2020, the residential investment incentives came to an end [26] be replaced in the first half of 2021 by a plan to reduce income taxes[27]. The new legislation permits a discount in income tax for the construction of PV systems, battery storage, and charging stations for electric vehicles up to 50,000 SEK per taxpayer every year [27]. Several reports have been studied for feasibility of PV systems. Jonas et.al studied PV system optimization towards nZEB in historical buildings[19]. Khan et al. studied the energy, economic and environmental aspects of BIPV with energy storage systems for residential and EV charging in Malaysia. The study concluded that grid-connected strategies are more profitable economically than grid-connected systems with battery storage [28]. Fiedler Et. Al investigated grid-connected PV systems with batteries for self-sufficiency (Fig. 2) in holiday homes, and the results obtained were promising and found to be equally profitable [29]. Lindahl et al. studied the economics of a centralized PV park in Sweden. The underlying costs of six PV parks commissioned in 2019 and 2020 were obtained by in-depth stakeholder surveys and analyzed through levelized electricity cost [30]. Kabir et al. studied the feasibility of a 40 kW (Fig. 3) PV Plant with a 3kWh battery in Karlstad and Arlanda, Sweden for a combined load of 121MWh in Sweden. The Karlstad system's capacity factor is 11.3%, with a yearly PV output of 39.23 MWh, whereas the Arlanda system's capacity factor is 10.1%, with a yearly PV output of 35.02 MWh[31].

1.2. *Electric vehicle status in Sweden*

Electric cars have seen major technological advancements in the last 20 years that have decreased costs, reduced environmental footprint, and enhanced usability [32]. The global market share of electric cars will more than double in 2021, marking an apparent acceleration of electric vehicle adoption worldwide – albeit some markets lag [33]. With the electrification of the transportation industry, power consumption is predicted to skyrocket to 550 TWh by 2030, up from 80 TWh in 2019 [34]. Several nations, like China, Norway, and Sweden, have already redesigned their national policies to encourage the adoption of developed electrified transportation networks (electric vehicles and charging infrastructure are seen as an entire system)[35].

Sweden aspires to become the first fossil-free welfare state in the world. Nearly a third of Sweden's present emissions of greenhouse gases come from the transportation sector. The sector in Sweden with the best possibilities of shifting to a fossil-free future is this one. The National Parliament has decided to cut domestic transportation's greenhouse gas emissions (aviation excluded) by at least 70% by 2030 compared to 2010[36]. Sweden passed a stringent climate law in 2018 that calls for net-zero emissions of greenhouse gases by 2045[37]. Sweden, a leader in the switch to electric cars, offers many great incentives for EV drivers. By purchasing a zero-emission four-wheeler, EV owners can save up to 50% on purchase subsidies, which equates to up to $6,700 in savings. Prior to July 1, 2018, this subsidy was approximately $4,500. The rise in subsidies demonstrates how committed the Swedish government is to lowering the country's CO_2 emissions[37]. More than 65% of EV users in Sweden have easy access to charging stations through home chargers or business EV chargers at the workplace and other public areas. Because of

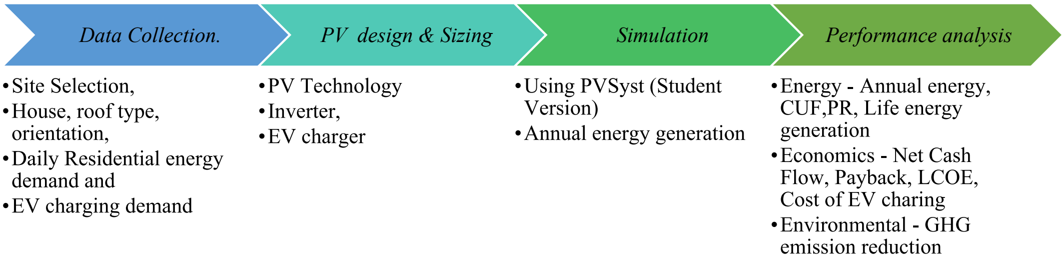


Fig. 2. Process flow illustrating the steps for the proposed research.

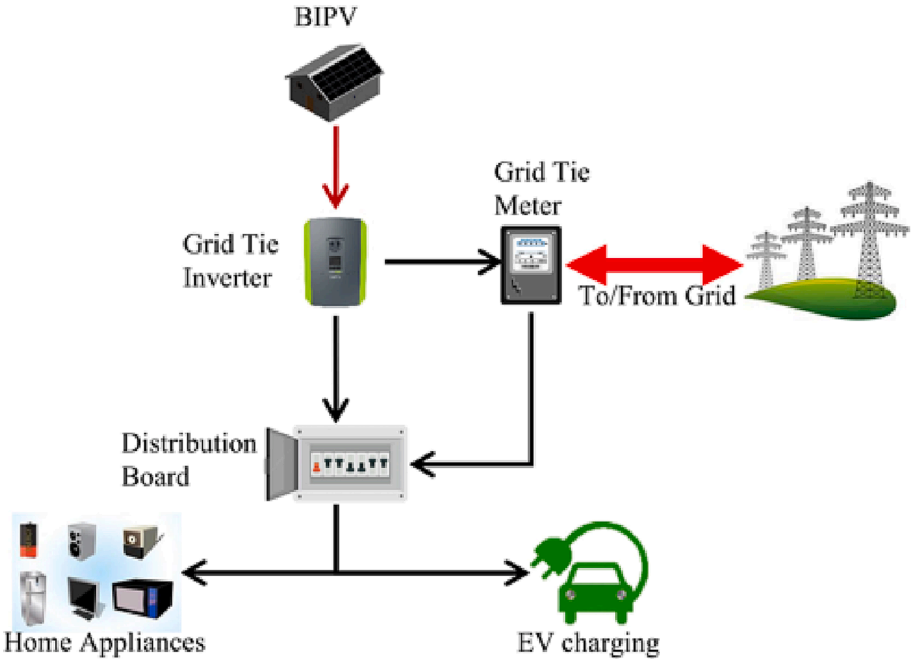


Fig. 3. Layout of grid-connected PV + EV Charging system.

the widespread use of EV charging stations, drivers no longer have to worry about running out of gas. As a result, purchasing an EV is a more sensible financial decision for drivers. Sweden is likewise spending money on affordable electric vehicle technology[38]. Egnér et al. studied EV adoption in Sweden with possibilities and barriers and stated that Range anxiety is the most significant rural barrier to charging options. Hence public charging stations in rural towns should preferably be located in regions where people regularly travel. Inadequate home charging options are the main urban hurdle; municipal public charging stations in urban areas should also be adjacent to densely inhabited regions with poor charging infrastructure [39].

The ratio of EVs per charger can be used to gauge how well the charging network will perform as the number of EVs on the road rises. Since fast chargers can accommodate more EVs than slow chargers, the charger power (measured in kW) per EV is crucial. Housing stock, average trip distance, and population density all affect how many chargers are necessary for each EV [40]. Lack of proper infrastructure, including charging stations, is one of the biggest obstacles to the adoption of e-mobility. But as EVs proliferate, so does the demand for charging. Building a sustainable solar-powered charging infrastructure that doesn't interfere with grid operation is essential in order to meet the needs of EVs. When actual EV charging data is scarce many different approaches to modeling EV charging can be adopted. Several studies utilize traditional driving behavior for combustion engine vehicles and data on behavior to generalize this to include EV charging. In [41], authors tracked the usage of 76 cars over a year in Winnipeg, Canada, and utilized this information to forecast PEV charging patterns and electrical range dependability. According to the study, appropriate stochastic modeling—using an iterative approach with conditional probability distribution functions pdfs—can increase prediction accuracy by 12% compared to current techniques. Authors in [42] researched plug-in hybrid electric vehicle (PHEV) behavior, and its influence on the electric grid. They assessed PHEV behavior under various daily driving patterns, which can give important information for PHEV design studies and grid prediction. Such findings can be used to forecast changes in total load demand in a specific region due to PHEV uptake [43]. In [44], the authors analyzed the Bernoulli distribution model to examine how various PEV factors, including the battery capacity, range, and driving habits of the vehicle, affect charging patterns for PEV charging. The simulation's outcomes demonstrate that the Bernoulli distribution model may be utilized to provide accurate charging schedules for PEVs. Grahn et al.'s [45] novel model was utilized to develop PHEV home-charging patterns by merging PHEV use with synthetic activity production of residents' electricity-dependent activities. The model indicated that the peak load in the nighttime hours will rise when more PHEVs are introduced. Regional studies have also been made regarding the impact of EV charging on the electric distribution system for several regions and countries, e.g. Netherlands [46], Portugal [47], Germany [48], Belgium [49], United States[50] and Canada [51]. However, the above indicated study can be integrated further with the PV system to avoid grid dependency and efficiently utilize the energy from PV for EV charting. Various studies have been found in literature on the possibility of using solar energy for EV charging. The stochastic model for photovoltaic power generation is based on high-resolution irradiance data for Uppsala, Sweden demonstrated in [52]. It is demonstrated that the adoption of a PEV enhances solar power self-consumption on both an individual and aggregate level, but the improvement is restricted due to the low coincidence between the photovoltaic power output pattern and the PEV charging patterns[52]. Brenna et al. investigated the feasibility of charging plug-in hybrid electric vehicles (PHEVs) with solar (PV) systems. According to the authors, the percentage of energy transferred from the PV system to the EVs varies from 1 to 3% to 56–72% (depending on the month. They determined that maximizing energy flow from PV systems to electric cars necessitates relatively long and low-power charges that allow them to leverage the hours when PV shelter output is greatest. To attain this purpose, however, an energy storage system is required [53]. The adoption of electric vehicles (EVs) and photovoltaic (PV) systems can help to reduce greenhouse gas emissions and combat climate change. However, there are some challenges to overcome in order to maximize the benefits of these technologies. One challenge is that the output of PV systems does not always match the demand for electricity from EVs. This is because PV systems produce electricity during the day, when solar radiation is strongest, while EV charging demand is often highest at night. This mismatch can be addressed by using energy storage systems to store electricity from PV systems for use later, when it is needed to charge EVs. Another challenge is that the cost of EVs and PV systems can be a barrier to adoption. However, the cost of these technologies is coming down, and there are a number of government incentives available to help offset the cost. Despite these challenges, the adoption of EVs and PV systems is a promising way to reduce greenhouse gas emissions and combat climate change. These technologies have the potential to transform our energy system and create a cleaner, healthier, and more sustainable future.

1.3. Gaps in existing research

The current body of literature exploring Sweden's solar photovoltaic (PV) potential has primarily focused on residential PV systems. However, a critical research gap exists as there has been limited investigation into the feasibility of incorporating an integrated PV system with electric vehicle (EV) charging capabilities to meet the daily energy needs of households. Furthermore, previous research has not explored the potential of bifacial panels in the Swedish context for such an integrated system. Although some authors have included the Rooftop PV system in their investigations, a notable gap in the literature is the lack of comparative analysis between bifacial and monofacial panels for households with EV charging demands. Addressing this gap is crucial to provide insights into the potential benefits of bifacial panels for households with EV charging demand and further advance the integration of sustainable energy solutions in Sweden.

1.4. Novelty and contribution of the research

The present study offers a unique and innovative approach by exploring the potential of bifacial solar panels to meet the energy demands of buildings in Sweden. What sets this study apart is the comprehensive assessment of the system, considering not just the energy aspect but also the economic and environmental factors. By comparing the performance of bifacial panels with monofacial panels, this study provides valuable insights into the potential benefits of bifacial panels for households with EV charging demand. Moreover, while the study primarily focuses on Sweden's context, the proposed methodology can be applied to other countries facing similar challenges in meeting the energy demands of houses with EV charging. This aspect of the study opens up exciting opportunities for the broader adoption of sustainable energy solutions and represents a significant contribution to the field of renewable energy research.

1.5. Objective and scope of research

This paper aims to fulfill the gaps and thus specifically focus on the following objectives:

- To design a grid-connected PV system to meet household electricity and EV charging demand.

-To simulate and optimize PV potential on different roof slopes using monocrystalline panels –Monofacial and Bifacial.

- To evaluate the economic and environmental aspects of the system. – Net cash flow, LCOE, payback period and cost of EV charging, CO_2 savings.

The scope of the study includes the feasibility of a PV system with EV charging in the Swedish context based on the energy, economics and environmental aspects.

2. Methods

The research question was approached by modeling and simulating grid-connected PV systems for household and EV charging requirements based on actual system components and with both techno-enviro-economical boundary conditions in Sweden. The simulation software PVSyst (Student version) has been used as a tool, which allows for detailed modeling of such systems, including all relevant boundary conditions.

2.1. Site selection and climate profile

In this study, a house in Örebro, Sweden, with gable type roof, having a slope varying between 15° to 45° [54] facing in South East, floor area of 100 m^2 (based on measurements from Google map) has been chosen. The typical residence in a multi-dwelling structure is 68 square meters, whereas the average one- or two-housing building is 122 square meters [55] Table 1 and Fig. 4 depict the selected site's coordinates and solar irradiation map (Fig. 5).

The weather in Örebro (Table 2), Sweden is humid continental, with mild to pleasant summers and chilly winters with average temperatures only a few degrees below freezing. July has the greatest average low temperature (12.3° C). January and February are the coldest months (with the lowest average low temperature) (-4.5 °C). The weather profile is depicted in Fig. 6.

2.2. Electricity demand for household and electric vehicle charging

This research considers daily household energy consumption and daily energy requirement for EV charging as input for analyzing total energy requirements. This study is based on daily and annual energy profiles to analyze building energy self-sufficiency. The electricity consumption in Sweden is temperature dependent [58] since a lot of electricity is used for heating. In Sweden, residential housing accounts for 15% of the total final energy demand, most of which (about 66%) is explained by the need for space heating and DHW. About a third of this is ascribed to space heating, with the remaining amount being DHW [59]. The estimated annual electricity consumption for a single house in Sweden is about 10.1MWh/year [60], representing an average of 27.6kWh/day electricity consumption. The hourly profile of a typical Swedish house is shown in Fig. 7.

The house is where the majority of home charging occurs. Charging at work is also relatively common: 35–40% of people surveyed claim to do so daily or weekly[61]. In Sweden, up to 80% of people who use electric cars reside in single-family homes, as opposed to 50% of the general population [61]. The discrepancy can most likely be attributed to the greater accessibility of private charging options. Very few electric car owners charge their cars at a publicly available street parking near their house. Most of the time, drivers gradually plugging-in in the evening between 5 pm and 12 am [62]. According to the National Travel Survey RVU Sweden 2011–14, the average passenger mileage by car per capita is 28.2 km per person per day [63]. Volkswagen ID.3 Pure Performance EV has been considered in this research, which has a battery capacity of 45kWh with an ideal range of 275 km and a consumption of 164Wh/km [64]. However, the range is affected by weather e.g. in cold weather, heating is required, which reduces the capacity. This study considers the ideal range according to the datasheet.

Daily energy required by EV can be calculated using the equation [28]:

$$\mathrm{E}_{\mathrm{EV}} = \frac{B_{EV} \times \mathrm{D}}{\mathrm{R}} \tag{1}$$

$$\mathrm{E}_{\mathrm{EV}} = 0.164 \times 28.2 = 4.63\mathrm{kWh}$$

Based on the above equation, the daily EV charging requirement is approximately 4.63kWh. Therefore, the total energy required for PV sizing is shown below.

$$\mathrm{E}_{\mathrm{Total}} = \mathrm{E}_{\mathrm{H}} + \mathrm{E}_{\mathrm{EV}} \tag{2}$$

Table 1
Site selection data.

Location Name	*Latitude and Longitude*	*Climate Zone*	*Elevation (m)*
Örebro, Sweden	59°15′08{\Prime} N 15°13′24{\Prime} E	Humid Continental	28

Fig. 4. Image showing location and orientation.

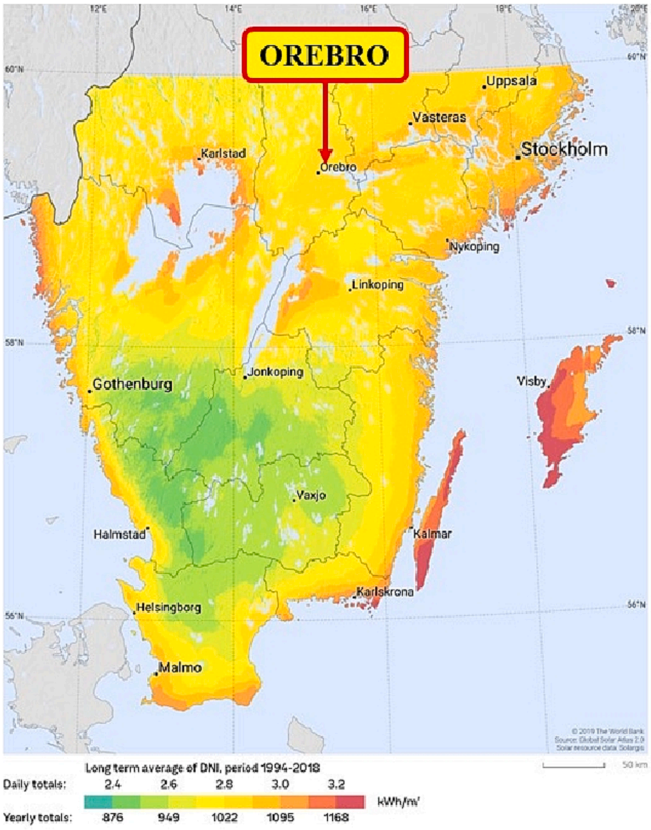


Fig. 5. Solar radiation map of Sweden [56]

Table 2
Site Solar Parameters [56]

Parameters	Unit	Orebro, Sweden
Direct normal irradiation	kWh/m^2	1055.5
Global horizontal irradiation	kWh/m^2	975.6
Diffuse horizontal irradiation	kWh/m^2	482.6
Global tilted irradiation at optimum angle	kWh/m^2	1218.9
Optimum Tilt of PV Modules	OPTA	43/180
Air temperature	°C	6.8

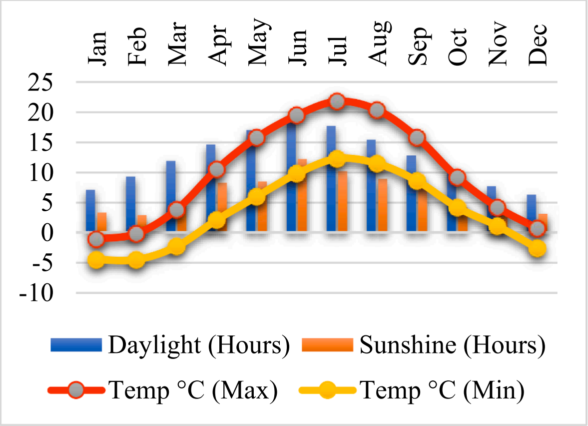


Fig. 6. Monthly temperature and daylight/sunshine hour [57]

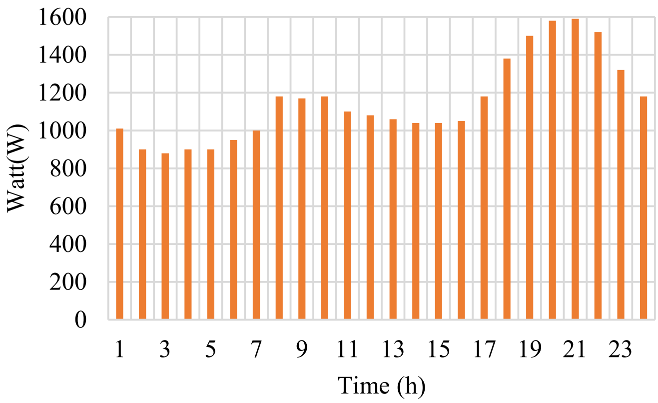


Fig. 7. Average hourly load curve [60].

$$E_{\text{Total}} = 27.6 + 4.63$$

$$E_{\text{Total}} = 32.2\text{kWh/day}$$

2.3. PV system detailed design

According to the IEA assessment, residential size ranges for single-family homes are 5-10kWp and 10-20kWp, and multi-family homes are 20-50kWp and 50-100kWp[13]. The typical villa system size was nine kWp, which appeared to agree with the typical system size documented in the Svanen database for Swedish single-family housing systems erected in 2019–2020, dominated by monocrystalline panels [13]. This study will proceed considering the feasibility of a 10kWp system towards achieving self-sufficiency of building for residential and EV charging loads.

The study site “Orebro” receives 100 mm of snow on average yearly, with most of it falling between December and March. In several studies from snow-rich locations with cold winters, PV systems suffer significant annual energy output losses, as reported in the literature. Snow’s effect on solar panels depends on how the array is set up and how much sunshine hits each cell. Strong correlation exists between a cell’s maximum throughput current (I) and the sun irradiation that it receives [65]. According to research conducted in Truckee, California, snow can cause yearly losses of 12–18% for tilt angles ranging from 39°to 0° (flat). The study also discovered a direct link between tilt angle and energy loss, but the relationship is modified by parameters such as array height and row spacing [66]. Lorenz et al. [67] studied the impact of snow on photovoltaic (PV) output in northeast Germany. They assumed that snow covered the PV panels 100% of the time when the air temperature was below zero degrees Celsius. This assumption decreased the root mean square error (RMSE) of intra-day hourly prediction values at a single site level from 11% installed power to around 7.5%. In another study [68], a PV test platform with seven modules at four different tilt degrees (0°, 15°, 30°, and 45°) was set up in Calumet, Michigan, USA, to track energy loss from snowfall for a year. According to the findings, snow-related yearly energy losses for tilted, unobstructed modules varied from 5% to 12%, with the sharpest tilt angle incurring the most negligible energy loss. Additionally, significant losses of up to 9.3% have been documented in moderate climates, compared to plants in mild temperatures, which generally have annual losses of less than 2% [69]. As a result, the panels can continue to be blanketed with snow until the surrounding air is warm enough for clearing to happen. As expected, ambient temperatures nearing zero degrees Celsius have a significant impact on how quickly PV panels clean [70]. These studies and their published findings suggest that snow losses might significantly affect energy yield and the investor and site owner's financial situation. Therefore, it is reasonable to consider snow effects when planning PV locations and to factor them into estimates, financial ROI calculations, and LCOE calculations. The plant's design criteria and technical details also affect how quickly snow is cleared. In general, but not always linearly, larger tilt degrees result in shorter snow cover times. Hence, this study includes the simulation of different roof slope and fixed azimuth. The impact of slope and azimuth on energy generation will be analyzed while comparing performance of mono-facial monocrystalline panel with bifacial monocrystalline panel in all conditions. A total of 6 cases with different conditions of panel tilt (15°,30°,45°), azimuth (-77°), and technology selection have been considered in this study, as shown in Table 3.

PVSyst student version 7.2 database has been used to select panels, batteries and inverters; further detailed simulation is carried out in the same software. This program collects meteorological data, device architecture, shading testing, loss determination, and economic assessment within a specified region. The simulation is run monthly for a year, and the results are summarized and stated in detail.

To design PV system, the Trina Solar monocrystalline monofacial solar panel TSM-410 DE09.05 with efficiency of 20.5%, panel degradation of 0.55% and Bifacial solar panel TSM-DEG15MC-20-(II)-410 with efficiency of 20.2%, panel degradation of 0.5% has been selected from PVSyst database. The maximum power capacity of both panels is 410Wp at STC. Each monofacial panel requires 1.76 $m^{2,}$ and the bifacial panel requires 2.03 m^2. Monocrystalline technology is more efficient, readily available and less expensive than other thin-film technologies. Monofacial solar cells only capture photons that hit the device's front surface. In contrast, the front and rear sides of a solar module's bifacial solar cells concurrently capture light from direct and reflected radiation. Bifacial solar cells also have the advantage of having lower operating temperatures and higher maximum power output due to reduced infrared absorption in the absence of aluminum back metallization [70–72]. Results and studies have demonstrated that bifacial modules can generate 10–20% more electricity than monofacial panels. The additional power may be as much as 30–40% if conditions are ideal and single-axis trackers are used [73]. Accordingly, Kostal Piko −10 three Phase Inverter has been chosen, a 10 kW inverter with an MPPT Voltage range of 90 V ~ 560 V, maximum efficiency of 98.5% with 2 MPPTs have current input of 12A each MPPT. Table 4 represents various building layouts and available area for PV system installation.

Table 3
Possible cases for study.

Case	Tilt/Azimuth	Technology
1	15 / −77°	Mono
2	30 / −77°	Mono
3	45 / −77°	Mono
4	15 / −77°	Bifacial
5	30 / −77°	Bifacial
6	45 / −77°	Bifacial

2.4. Assumptions in this research

Table 5 shows a list of parameters considered in this study for designing and simulating the PV System for residential and EV Charging energy requirements.

3. System performance

3.1. Energy assessment

3.1.1. Annual energy yield

Annual solar power production from a PV system that has been installed can be expressed on a daily, monthly, or yearly basis. It is determined by module specifications and the system's solar irradiation at a specific location [74].

3.1.2. Capacity utilization factor (CUF)

The ratio of anticipated annual energy generated by a solar PV system to annual energy generation at rated capacity is known as CUF [75]. This is a metric for how well a system functions under ideal circumstances at a certain location. It is expressed as a percentage.

$$\mathrm{CUF} = \frac{E_{Out}}{E_{Full}} \times 100 \tag{3}$$

$$E_{Full} = \text{Installed Capacity} \times 365\,\text{days} \times 24\,\text{Hours} \tag{4}$$

3.1.3. Performance ratio (PR)

PR can be defined as the ratio of actual or predicted energy produced by the system to the system under normal operating conditions to the theoretical energy output generated by the system based on local climatic conditions of the place [76]. It is represented below

$$\mathrm{PR} = \frac{\mathrm{Y_f}}{\mathrm{Y_r}} \tag{5}$$

3.2. Economic assessment

The cost analysis for grid-connected PV Systems with EV charging has been discussed in this section. The economic analysis is a critical step in developing a solar photovoltaic project since it determines if the project will be financially feasible in the long term. It is helpful for the user to do the cost analysis to choose the optimized capacity for their needs. However, in this study, the PV with EV charging system only includes the initial Cost of the system, annual maintenance cost and benefits from Feed-in-Tariff. The component replacement costs have been excluded. Other parameters, such as electricity bills and fuel savings, have been considered in the evaluation. A project's economic feasibility is determined by its NPV, LCOE and payback time. NPV is the difference between the current value of cash inflows and cash outflows over time. The project is economically feasible if the NPV is positive. The estimated system breakdown cost is shown in Table 6 (Soft costs taken from IEA report [14]).

3.2.1. Payback period

The payback period is when it takes to recover the money invested in a project, typically evaluated in years. This is based on the yearly energy savings of the system. The sooner the project's original investment is repaid, the more profitable it becomes.

$$\mathrm{PB\ or\ PB-D\,(years)} = \frac{\mathrm{C}_{system}}{Annualprofit(SEK)} \tag{6}$$

Table 4
Representation of building and required area.

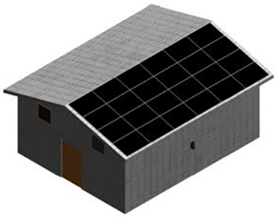
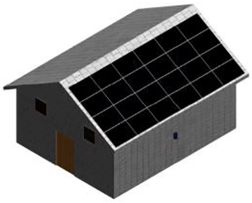
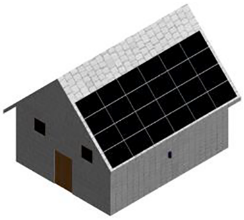
PV System Layout Layout	Layout 1	Layout 2	Layout 3
Roof Layout			
Roof Slope	15°	30°	45°
Usable Area	67.8 m^2	75.6 m^2	92.6 m^2
PV Configuration	11 Strings X 2 In Series = 22 Units	11Strings X 2 In Series = 22 Units	11 Strings X 2 In Series = 22 Units

Table 5
Inputs and assumptions for the system simulation.

Parameters Building Load	House	Single house	References [54]
	Available Roof Area	Shown in Table 4	–
	House design	Typical house with gabled roof	[54]
	Roof Direction	Refer Fig. 4	–
	Building daily load	27.6kWh	[60]
EV Charging Load	Car	Volkswagen ID.3 Pure Performance	–
	Daily Commute distance	28.2 km	[63]
	Daily EV Charging load	4.63kWh	–
Car Battery Specifications	Battery Size	45kWh	[64]
	Range	275 km	[64]
	Charger Type	Type 2	[64]

Table 6
Initial Cost Breakdown for PV System with Monofacial Panel versus Bifacial Panel.

PV System	Case 1,2,3	Case 4,5,6
Cost category		
Hardware	SEK	SEK
Module type	Monofacial	Bifacial
Modules cost	58,630	104,390
Inverter	28,995	28,995
Mounting materials	4012.8	4012.8
Other electronics	15734.4	15734.4
Subtotal hardware	107372.2	153132.2
Soft costs	Average [SEK/Wp] [12]	Average [SEK/Wp]
Installation work	3.5	3.5
Permits and reporting	0.13	0.13
Working travel time	0.23	0.23
Planning and sales	0.48	0.48
Shipping to customer	0.16	0.16
Travel costs	0.09	0.09
Other	0.04	0.04
Supplier margin	1.17	1.17
VAT	3.22	3.22
Subtotal soft costs	9.02	9.02
Total	202623.4	248383.4
System Size (Wp)	10,560	10,560
EV Charger price	7345	7345
Total System Cost	209,968	255,728

3.2.2. *Net cash flow*

Net cash flow is the cash inflows and outflows over the period. It's an important parameter to estimate the payback period of a project and profit over time.

$$NCForNCF - D = C_{inflow} - C_{outflow} \tag{7}$$

Cash inflows include savings on electricity bills, transportation and revenue generated by selling energy to the grid. In contrast, outflow includes any maintenance cost, replacement cost, or buying back power from the grid. Total bill savings over 25 years (based on the Solar panel datasheet) can be estimated using Equation (8).

$$C_{Bill} = (C_{Res} + C_{Transport}) \times 25year \tag{8}$$

Replacement cost has not been considered. Furthermore, net cash generated over the lifecycle of 25 years has been evaluated as per below equation (9):

$$C_{Net} = C_{Bill} + C_{Grid} - (C_{Maintaince} \times 25) - C_{System} - C_{Replacement} - C_{import} \tag{9}$$

$$C_{Import} = E_{Import}kWh \times Tariff(SEK) \tag{10}$$

$$E_{Import} = \sum_{j=1}^{n} \left[E_0 \times (1-\delta)^j\right] - (E_{user} \times 25) \tag{11}$$

3.2.3. *Levelized cost of energy (LCOE)*

The main instrument for evaluating the plant-level unit costs of various baseload technologies throughout their operational lives is the LCOE. The LCOE represents the financial costs of a general technology, not the expenses of a particular project for a specific market. The LCOE is conceptually closer to electricity production costs in regulated electricity markets with stable tariffs, for which it was developed than the variable prices in deregulated markets due to the equality between discounted average costs and the regular remuneration over lifetime electricity production, which is at its core. The LCOE idea may theoretically be used in deregulated markets by changing the discount rate for the hidden Cost of price volatility [77]. According to IEA, LCOE equation (12)is represented below [77]:

$$LCOE = \frac{\sum (Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t)^*(1+r)^{-t}}{\sum MWh \times (1+r)^{-t}} \tag{12}$$

Over time, all solar systems deteriorate. This panel degradation is denoted as δ, and its energy output for year "n" has been calculated using the equation [78]:

$$E_n = E_0 \times (1-\delta)^n \tag{13}$$

Where E_n is the amount of power produced that year, and E_0 is the amount produced in the first year. Therefore, the total energy produced over the system's lifetime (n years) is:

$$E_L == \sum_{j=1}^{n}\left[E_0 \times (1-\delta)^j\right] \tag{14}$$

3.2.4. Costs for electric vehicle charging

An electric vehicle’s fuel efficiency is measured in kilowatt-hours (kWh) per kilometer. The Cost of energy (in SEK per kWh) and the efficiency of the vehicle (how much power is utilized to drive per km) must be known to compute the Cost per mile of an EV [79].

$$C_{EV} = \frac{B_{EV} \times LCOE}{R} \tag{16}$$

3.3. Environmental assessment

The substitution of energy from conventional power plants with solar energy for clean electricity has a substantial positive impact on the environment. Additionally, using solar energy to charge EVs contributes to net-zero mobility. Because the PV Plant employs solar energy to meet the demand for EV charging, emission factors are utilized to calculate the reductions in carbon dioxide emissions that result from not using grid electricity. The average rate of a specific GHG emission for a particular source, is known as an emission factor and can be described per equation (17) [80]. Sweden had average emissions in 2021 of 29 g CO_2eq/kWh. Hydropower (46.7% of total energy production) was the primary renewable energy source, accounting for 68% of all energy production. Sweden is a leader in the development of renewable energy [81].

3.3.1. Greenhouse gas savings by electric vehicle

In 2020, new passenger car emissions in Europe decreased by 12% to 107.5 gCO_2/km on average, following a modest increase in emissions from 2017 to 2019 that brought them up to 122.3 gCO_2/km. For 2020–2024, Regulation (EU) 2019/631 establishes a fleet-wide objective of 95 g CO_2/km and more vital fleet-wide targets for 2025 and 2030 [82].

Total annual GHG savings for the PV system comprises of GHG savings due to PV system and the use of EV. The equivalent saved CO_2 emissions for PV Systems have been calculated using the formulae.

$$\text{GHG}_{Energy} = E_L \times F_{grid} \tag{17}$$

$$\text{GHG}_{EV} = D_{lifetime} \times \text{EF}_{Fuel} \tag{18}$$

$$\text{GHG}_{Total} = \text{GHG}_{Energy} + \text{GHG}_{EV} \tag{19}$$

4. Results

The possibility of a solar PV project is evaluated by its technical, economic and environmental sustainability. The average yearly values of parameters such as energy yield, capacity utilization factor and performance ratio, payback period, LCOE, cumulative cash flow and GHG savings has been studied for the chosen location with two different PV technology to analyze the feasibility of the system.

4.1. Energy analysis

Considering losses in each case, energy analysis has been estimated, and available energy at inverter output has been taken for further analysis. The energy production of the system is simulated using PVSyst. Fig. 7 shows that energy generation by PV System with EV charging system layout 1 is higher than the other two systems daily. Also, due to higher energy generation, it will reduce grid dependency and increase solar payback revenue. Table 7 below shows the comparison of loss concerning each case.

Fig. 8 depicts that from April to August, the system will generate sufficient energy to meet the user needs, while in other months’ energy generation is too low, which can only meet between 9% in January to 56% in September. Therefore, remaining energy will be imported from the grid.

Fig. 9 shows that energy generation by PV systems for bifacial panels is higher than the system with the mono-facial panel. PV systems, in all cases, cannot meet the energy demand. Therefore, energy from the grid is required to meet the excess energy.

Considering the degradation of PV panels, the energy generation output will reduce over the lifetime, affecting the imported energy from the grid. Panel degradation factor has been applied to estimate the annual energy generation in Fig. 10.

Table 7
Loss analysis of different cases.

Parameters	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*
Global horizontal irradiation (kWh/m^2)	932	932	932	932	932	932
Global incident in coll. Plane	2.1%	2.0%	−0.45%	2.10%	2.00%	−0.45%
Far Shading/Horizon	−0.01%	−0.03%	−0.06%	−0.01%	−0.03%	0.06%
Near Shading irradiance loss	0.00%	0.00%	0.02%	−0.35%	−1.48%	−2.96%
IAM Factor global	−3.97%	−3.09%	−2.67%	−3.93%	−3.09%	−2.71%
Ground reflection on front side	0.00%	0.00%	0.00%	0.12%	0.68%	1.77%
Bifacial Panel	–	–	–			
Global incident in ground (kWh/m^2)	–	–	–	579 on 143 m^2	576 on 143 m^2	575 on 143 m^2
Ground reflection loss	–	–	–	−70.00%	−70.00%	−70.00%
View factor for rear side	–	–	–	−67.20%	−69.28%	−72.85%
Sky diffuse on rear side	–	–	–	1.45%	8.61%	24.81%
Beam effective on rear side	–	–	–	1.67%	16.34%	45.41%
Shading loss on rear side	–	–	–	−5.00%	−5.00%	−5.00%
Global irradiance on rear side(kWh/m^2)	–	–	–	150	150	218
Effective irradiation on collectors (Wh/m^2 X 53 m^2)	*914*	*921*	*902*	*912*	*914*	*891*
Efficiency at STC	20.08%	20.08%	20.08%	20.17%	20.17%	20.17%
Array nominal energy (at STC efficiency)	*9.64*	*9.72*	*9.52*	*10.87*	*11.04*	*11.14*
PV loss due to irradiance level	−1.76%	−1.72%	−1.75%	−1.62%	−1.62%	−1.60%
PV loss due to temperature	−4.29%	−4.71%	−4.90%	−4.09%	−4.29%	−4.11%
Module quality loss	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%
Mismatch loss, modules and strings	−2.10%	−2.10%	−2.10%	−2.10%	−2.10%	−2.10%
Mismatch back irradiance		0.00%	0.00%	−1.45%	−1.67%	−2.13%
Ohmic wiring losses	−0.72%	−0.77%	−0.80%	−0.77%	−0.81%	−0.81%
Array virtual energy at MPP(MWh)	*8.88*	*8.91*	*8.71*	*9.89*	*10*	*10.06*
Inverter loss during operation	−4.83%	−4.85%	−4.91%	−4.70%	−4.69%	−4.67%
Night Consumption	0.00%	−0.17%	0.00%	0.00%	0.00%	0.00%
Available energy at inverter output (MWh)	*8.45*	*8.48*	*8.28*	*9.42*	*9.53*	*9.59*

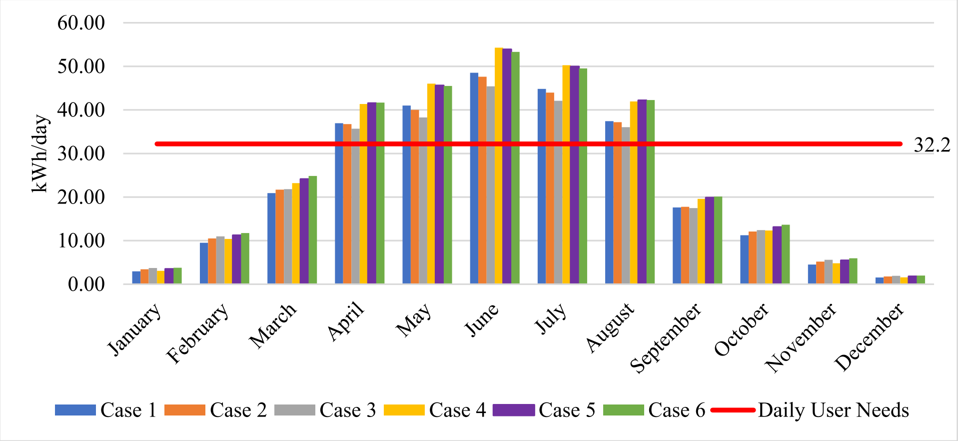


Fig. 8. Daily average energy generation for each case compared to energy demand by the user in kWh.

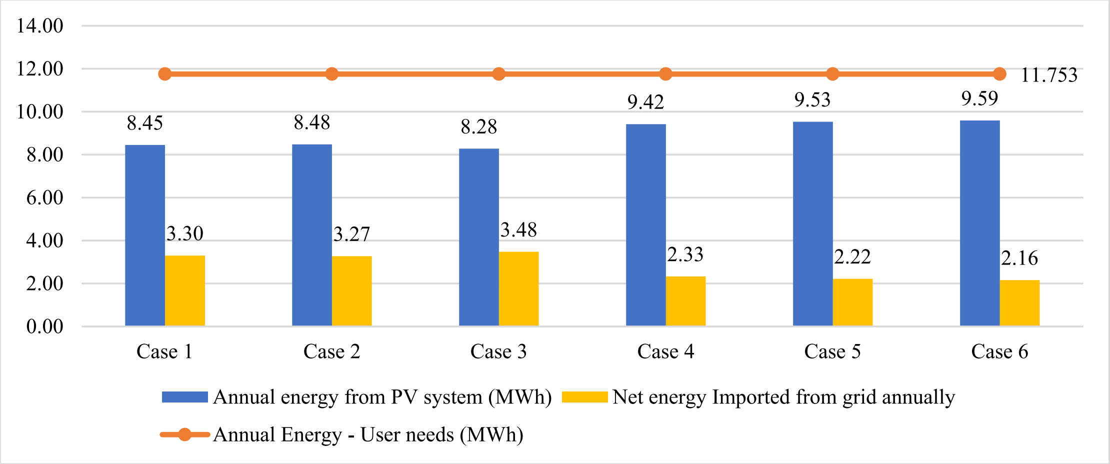


Fig. 9. Comparison of annual energy generation and energy imported from the grid vs. user needs in MWh.

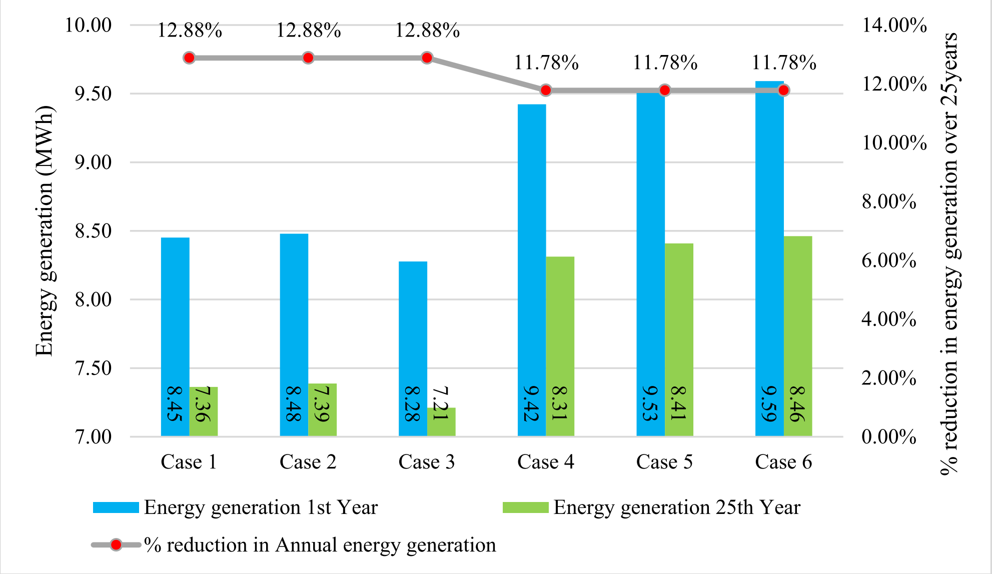


Fig. 10. Annual energy generation comparison between 1st year and 25th year.

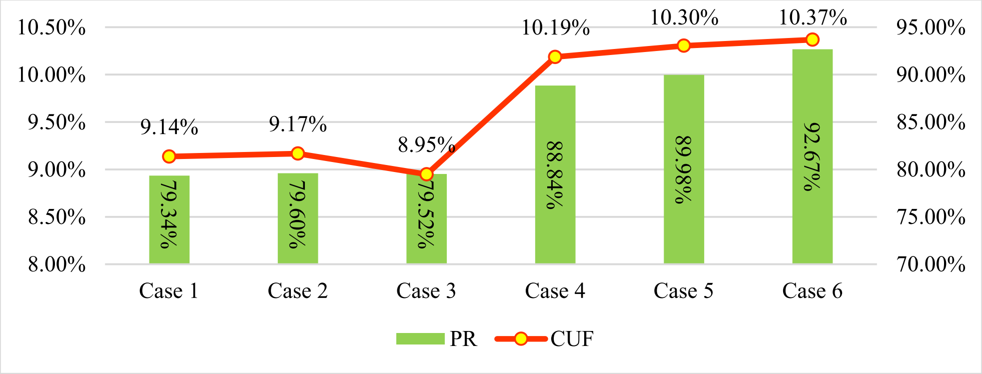


Fig. 11. Comparison of CUF and PR of different cases.

4.1.1. *Capacity utilization factor and performance ratio*

At full load, the system's plant capacity is 92505.6 kWh. The CUF for System in Cases 1 through 6 are therefore depicted in Fig. 11. Fig. 11 illustrates how PVSyst evaluated the PR of the two systems.

4.2. *Economic analysis*

The profitability of the installed PV system can be indicated by economic analysis. It gives an idea about recovering any system's invested amount and profit gain. The overall cost break-up of the proposed system is shown in Table 8. The average price of electricity in Sweden in June of 2022 was 0.2525€ per kilowatt hour, equivalent to 2.79SEK/kWh [83]. PV installations are eligible for a 15% tax deduction, whereas electric car batteries and charging stations are eligible for a 50% tax deduction. Private individuals can claim this deduction once per person and year. The maximum permitted amount per year is 50,000 SEK. Also, excess PV electricity can be injected into the grid with offers from utilities, 0.6 SEK/kWh + Green certificates + Feed compensation from the grid owner[14].

Also, on average, as reported in the literature, a 28.2 km daily commute distance has been considered for calculation [63]. The gasoline price in Sweden is 20.303 SEK/Liter, taken on April 17, 2022 [84]. An economical car, on average, consumes 5.0L/100 km of fuel. Therefore, on average, a commuter would spend SEK 39.76/day on transportation. Accordingly, annual savings have been estimated at SEK 10,449/year.

To analyze the economic aspects of the proposed PV System, Net cash flow, LCOE and payback period will consider both cases of capital cost without discount and with a 15% discount.

Energy generation will reduce over time due to panel degradation, while energy import will increase from the grid over the plant's life cycle, which affects the economy. Following equation (9), cumulative cash flow over 25 years has been represented in Fig. 12 and Fig. 13, respectively. It depicts the cash flow from the start of system installation, which was negative until the initial investment was recovered and profit was made over the lifetime. The payback period with and without discount rates for all the systems is further represented separately in Fig. 14.

Fig. 14 below represents the PV system's total profit generated in 25 years, with the payback period in years. PV system with discount and without discount has been demonstrated in various cases. PV system with discounted system cost has reduced payback period and higher net profit.

LCOE of the system and Cost of EV charging has been estimated using equations (12) and (16) for the systems in Case 1 to 6 (Fig. 15). PV Systems with and without discount offered the highest LCOE in case 4 and lowest in case 2. Similarly, the Cost of EV charging was also found to be lowest in case 2 and highest in case 4.

4.3. *Environmental analysis*

The ability to generate clean electricity using solar energy instead of conventional power plants is an environmental benefit that outweighs all others. Additionally, using solar energy to charge EVs contributes to net zero mobility. The carbon-dioxide reduction per MW of power to the atmosphere is determined per Equations (17),18,19.

5. Discussion

The paper presented a grid-connected 10kWp PV System with EV charging for a typical house in Sweden to meet the total demand of residential and EV charging load. The outcome of this research has provided insight into the PV system's energy, economics and environmental aspects. However, the results should be interpreted with caution due to the limitations mentioned in current research. This section reflects the research paper.

Six cases were studied in the paper with two different technologies. Monofacial and Bifacial monocrystalline technology performance, has been simulated to analyze the energy generation in different slopes/azimuths. The bifacial PV system generated a minimum of 10% higher energy than the Monofacial PV system. Fig. 8 signifies the average daily energy generation by the PV systems compared with user needs. It has been observed that during the summer months, from April to August, the system can generate sufficient energy to meet the daily energy demand

Table 8
Data required for economic analysis for PV system with EV Charging infrastructure.

Parameters	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*	*Unit*
Years of Service, N	30	30	30	30	30	30	Years
Initial Cost of System, C_{system} Without discount	179,968	179,968	179,968	255,728	255,728	255,728	SEK
*Initial Cost of System, C_{system} With discount 15%	152,973	152,973	152,973	217,369	217,369	217,369	SEK
Electricity bill saving/Year (1st Year), C_{Res}	23578.6	23658.6	23094.5	26288.3	26594.2	26759.3	SEK
Maintenance Cost/year[14], $C_{Maintenance}$	64	64	64	64	64	64	SEK/kWp/yr
Cost Saving for Transportation/Year, $C_{Transport}$	10,449	10,449	10,449	10,449	10,449	10,449	SEK
Cost of energy import annually (1st Year), C_{import}	9,212	9,132	9,696	6,503	6,197	6,032	SEK

*Represented a discount rate of 15% on the capital cost of the system.

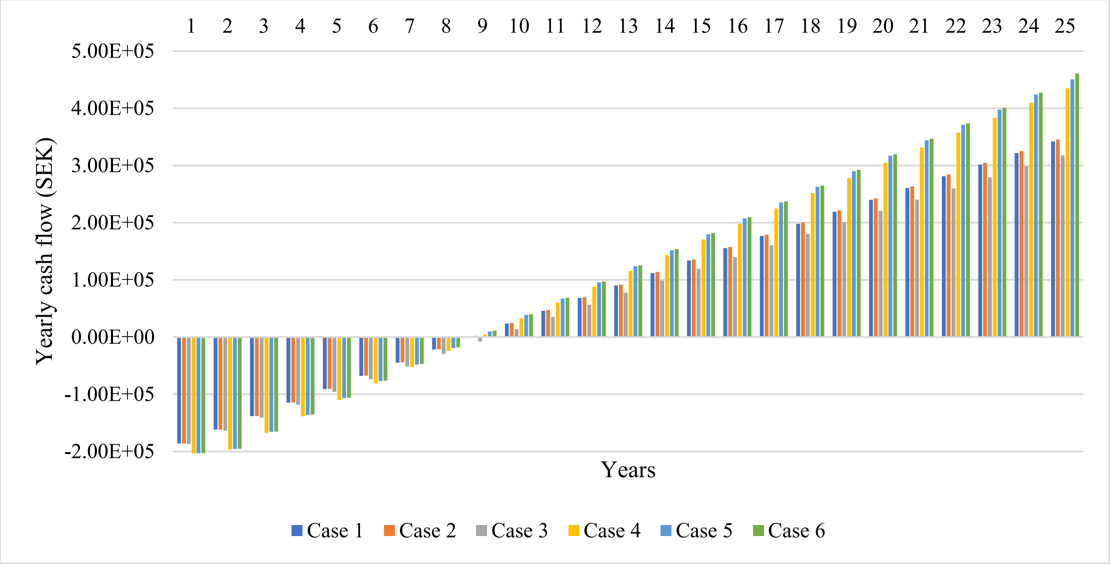


Fig. 12. Cumulative cash flow all cases for PV system without discount.

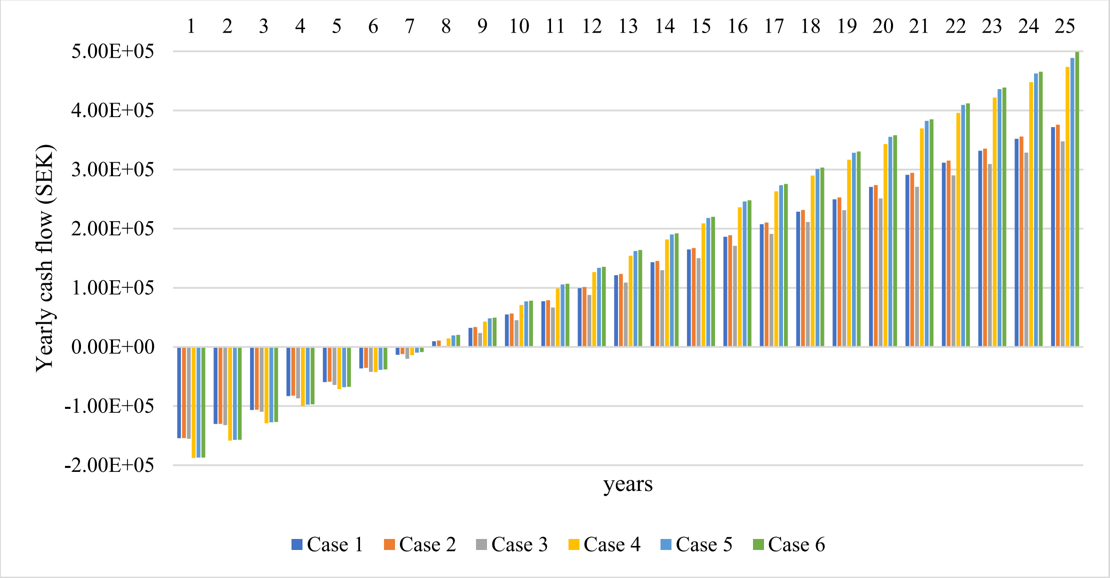


Fig. 13. Cumulative cash flow in all cases for PV system with a 15% discount.

of 32.2kWh. In contrast, for other months, the energy generated by PV systems could not meet the building and EV charging demand in all cases. Therefore, PV system grid dependency cannot be avoided as excess required energy must be imported. Fig. 9 represents annual energy generation and energy imported from the grid. Case 6, a bifacial PV system with a roof slope of 45° generated the highest energy of 9.59MWh annually whereas case 3 generated the least annual energy of 8.28MWh. However, none of the systems could meet 100% yearly demand of 11.753MWh. The performance ratio of all Monofacial monocrystalline panels is approximately 79% whereas all bifacial monocrystalline panels' performance ratio is higher, ranging between 88% and 92% due to increased energy yield. It is observed from Fig. 10 that the reduction in energy generation by the PV system for the Monofacial panel was 12.88% after 25 years, while % drop in energy generation by the Bifacial PV system was 11.78% which performed better in terms of meeting energy needs. CUF of the PV system is approximately 9.4% for Case 4 to 10.88% for Case 6. Net cash flow, LCOE and payback period are important economic performance indicators in many other PV-based grid-connected residential studies. For instance, a similar survey for PV systems in Karlstad, Sweden (40 kW PV and 3 kWh battery size) has LCOE (0.95 SEK/kWh) with a payback period of 10.5 years [31]. In this study, the LCOE of the system was presented in Fig. 14, which shows the LCOE of a PV system with a discounted rate of approximately between 0.8988 and 0.9851EK/kWh, whereas without discounted PV systems offer a slightly higher value between 1.057 and 1.159 SEK/kwh. Net cash flow over the life of the PV system, which is presented in Fig. 12 found to be between SEK 317,648 for case 3 and SEK 458,749 in case 6 for the PV system without discount; however, the system with discounted price shows higher returns with a total value of SEK 497,108 in case 6. The payback period for all the systems is represented in Fig. 14, where PV systems with discounted prices show a lower payback period of 7.3 years in case 6. Also, policies regarding discounts or tax rebates on components support reducing the payback period and increasing profitability for the house owners. Furthermore, environmental impact has been evaluated in other studies in other locations. In this study, environmental analysis has been conducted and

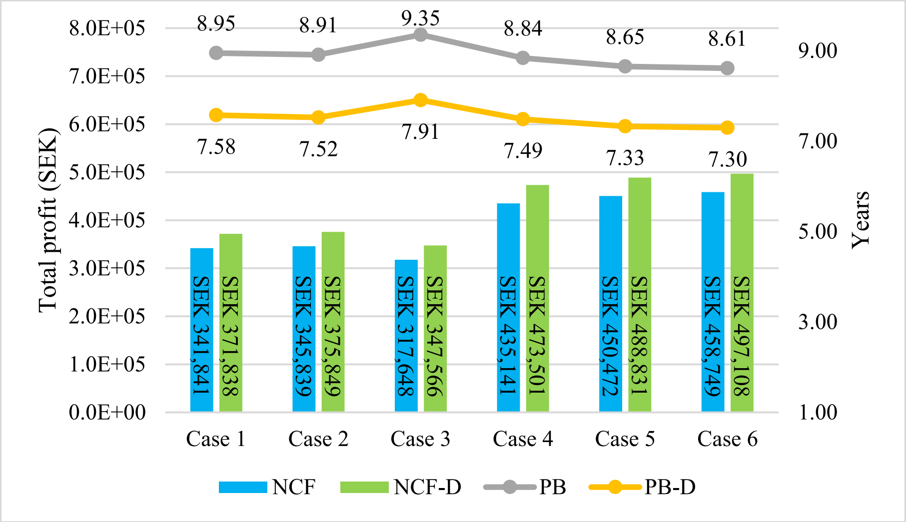


Fig. 14. Comparison of net cash flow and payback period for PV systems without discount and with a 15% discount.

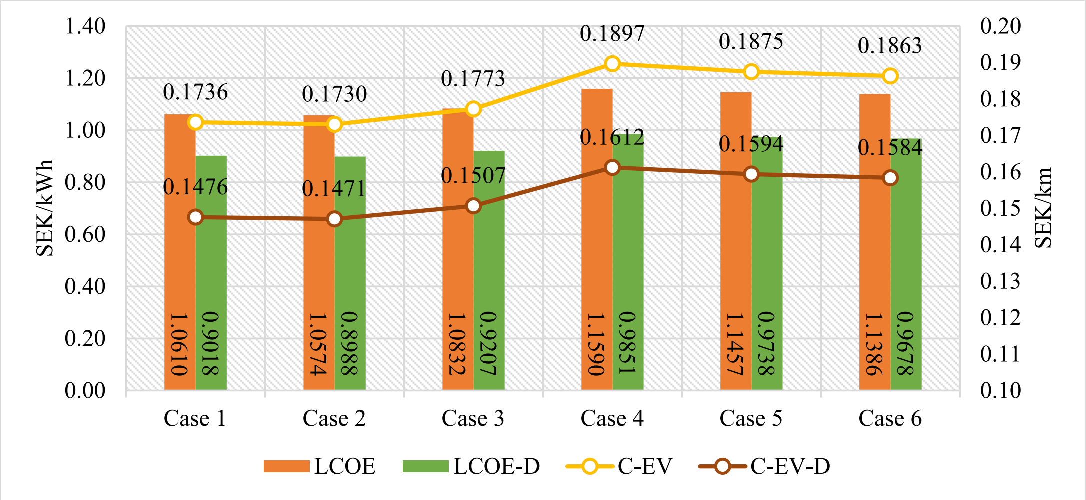


Fig. 15. LCOE and Cost of EV charging of the PV system without tax discount and with a 15% discount.

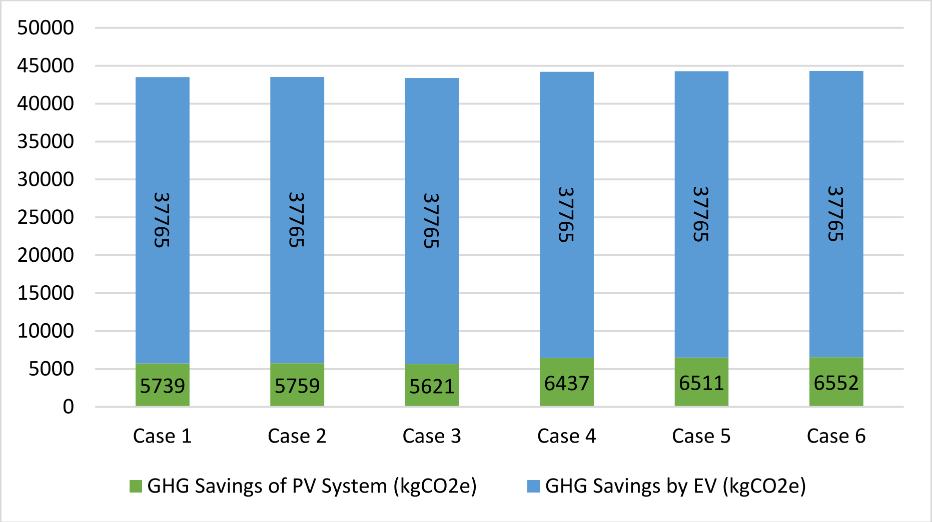


Fig. 16. Total GHG savings of the PV system for Residential and EV charging load and fuel.

represented in Fig. 16 to estimate the potential reduction in GHG due to installing PV Systems and avoiding gasoline in transportation. GHG reduction due to PV is lower as Sweden generates most of the electricity from renewable energy, reducing the grid emission factor compared to other countries that depend on coal and gas for electricity production. Due to climatic conditions, there are several implications in this research meeting energy demand during low light days that need further exploration. Energy management for the household with ev charging shall be further studied. Integrating artificial intelligence-based charging in PV systems can be further explored for energy management.

6. Limitations of the research

The process presented is considered a case study of a Swedish household with the following limitations. However, the methodology presented can be implemented using country-specific input data from other countries.

- Input data for the simulation work depends on the data available through various literature presented in Table 5.
- Energy analysis has been conducted based on pre-defined losses in the software output, which may vary based on actual conditions.
- The Cost of the system has been taken from online sources for economic analysis, which may affect the accuracy of the results. The inflation rate has been excluded from the financial analysis.
- Fuel price is dynamic and usually changes over time. This study considers fuel prices based on specific dates and times and considered contact for the lifetime.
- Environmental GHG emission reduction is based on the result achieved through software simulation; actual results may vary. The result of this paper could be used as a benchmark for further research.
- The limitation of the study includes the Greenhouse gases emitted during the fabrication of PV modules cells, BOS, and during transportation and disposal are not considered here.
- The cost of EV has been excluded.
- Energy management of the PV system with EV charging has been excluded.

This study offers a means of advancing SDGs 7 (“cheap and clean energy”), 11 (“sustainable cities and communities”), and 12 (“responsible consumption and production”). It will serve as a benchmark for practical implementation and could pique the scientific community’s and consumers’ intense interest. Electric vehicle charging with renewable energy lowers the grid’s excess load and promotes net-zero transportation.

7. Conclusion

In order to examine the techno-economic and environmental performance in Swedish context, the article investigates the performance of 10kWp grid-connected PV system in terms of energy, economics and environment. This study used two technologies Monofacial and bifacial monocrystalline panel with three different roof slopes and azimuth. Total of 6 cases were studied and concluded as below.

- PV systems with bifacial panels have higher annual energy generation compared to Monofacial panels. The highest energy generation was observed in case 6 with bifacial panels (9.59MWh) as the energy was generated by both sides of the panel whereas lowest energy generated in case 3 (8.28MWh). Also, PR was found to be higher in PV system with bifacial panel ranging between 88% and 92% while PR for PV system for Monofacial panels was approximately 79%. Similarly, CUF of case 4,5 and 6 were comparatively higher than CUF of PV System in case 1,2,3. Bifacial panels performed better at a higher slope of 45° considering same azimuth whereas Monofacial panels performed better at 30° slope.
- Economically, net cash flow, LCOE, Payback period and cost of EV charging was studied for economic performance of the panel without discount and with 15% discount for the proposed system. Discount factor improved the profitability of the system. Also, PV systems in all cases generated positive net cash flow over the lifetime of 25 years. Case 6 had the highest net cash flow, at SEK 497,108, while Case 3 had the lowest. The lowest LCOE for PV systems at a discounted rate was 0.8988 SEK/kWh, and the cost to charge an EV was 0.1471 SEK/kWh in the case 2. Similarly, payback period of 7.3 years was found to be lowest in case 6 whereas longest payback period of 9.35 years in case 3. However, economically BIPV systems found to be feasible with and without discount.
- Environmentally, all systems have shown GHG reduction over the system’s lifetime compared to the same energy generated by coal and gas plan. However, GHG reduction due to transportation was higher compared to PV system as grid emission factor for Sweden very low.
- Even though annual performance evaluations confirmed that a 10kWp PV system could meet between 70% and 80% of the annual energy requirements. It is noted that system performance was relatively low during the winter and days with little light. Because of this, the system is completely grid-dependent. In order to meet the energy demand during low light circumstances, further research might be done on solar and wind hybrid systems with battery storage systems. This study can be expanded further to assess the viability of a solar PV system for a community microgrid because, in the summer, the system produced 50% more energy than was required. It is possible to investigate further the energy management features of EV charging. Artificial intelligence-based charging, which comprises forecasting, charging, and scheduling, can also be investigated to charge the vehicles during off-peak hours and lessen the additional stress on the grid.

Authors’ contribution statement

Sanjay Khan: Conceptualization, Software, Methodology, Writing - Original draft preparation. **K Sudhakar:** Investigation, Data curation, Writing - Reviewing and Editing, Supervision. **Mohd Hazwan bin Yusof:** Visualization, Supervision, Validation, Writing - Reviewing and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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