JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

SUSTAINABLE ENERGY ENGINEERING STREAM

Life Cycle Assessment of Photovoltaic Integrated Light-Duty Vehicle (In Case of NISSAN Ethiopia)

By:

Tolawak Gobena

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Sustainable Energy Engineering

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Advisor: -Prof. Dr.A. Venkata Ramaya (Ph.D)

Co-Advisor: - Debela Geneti (Ph.D. Candidate)

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DECLARATION

This is to certify that the research paper entitled;-‘‘Life Cycle Assessment of Photovoltaic Integrated Light-Duty Vehicle (In Case of NISSAN Ethiopia)’’ is my original work and has not been presented for a degree in any other university and all sources used for the thesis has been duly acknowledged.

Tolawak Gobena ____________________

Student Signature

This is actual work done by Tolawak Gobena Geleta under my guidance for the partial Fulfillment of the award of the degree of Master of Science in Sustainable Energy Engineering

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ABSTRACT

This study focuses on a life cycle assessment of vehicle integrated photovoltaic solar energy on-board and off-board to save energy, improve economic and environmental aspects of Nissan vehicles in Ethiopia. Solar energy on-board and off-board, utilizing photovoltaic (PV) is proposed to be employed for fuel economy, extend driving ranges, reduce greenhouse gas (GHG) emissions, and ensure better economic value. The objective of this study is to investigate the technological benefit of vehicle integrated photovoltaic solar energy through the life cycle assessment. The methodology employed in this work calculated the total area of the NISSAN vehicle used for the installation of solar PV. To test the sufficiency of the power produced, direct normal irradiance (DNI) was computed, taking into consideration the factor of shade and wind speed. Two months of data were collected in Ethiopia (February and July) to assure the economic return on investment (ROI) value of installing onboard PVs, with everyday data for all systems. The result shows that the power loss due to the added mass of PV module, mounting, battery, electric motor, and increase in the frontal area of vehicle ranges from 140.8 W to 156.28 W, and the power generator from PV ranges from 492.6 W to 759.3 W. The net power gain ranges from 336.36 W to 613.63 W, which is the difference between power gain and power loss. The findings show that increasing the daily driving range of a conventional passenger EV from 4 miles to 22 miles by adding on-board PVs to cover less than half (about 3.261 m^2) of the estimated horizontal surface area of a conventional passenger EV. Solar energy is utilized based on the vehicle's specifications, location, season, and total driving time. When fuel costs were below $6.0 per gallon in July, the return on investment (ROI) of adding PVs onboard with an ICE vehicle during its lifetime ranged from - $50.86 to $66.61, and in February, it ranged from $42.76 to $252.27. Furthermore, the return on investment (ROI) adding PVs on-board with plug-in electric vehicles and electric vehicles had negative to positive values in the range of $48.98 to $135.65 and $45.45 to $154.72 in July, and $56.46 to $398. The proposed PV installations showed a short payback period of 5.3 years. After PV installation, specific CO_2 saving with PV energy is 470 g/kWh and the CO_2 emission avoided is 8701 Kg/Year.

Keyword: - life cycle, Vehicle integrated PV, on-board, and off-board, and Carbon dioxide emissions

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ABBREVIATION /NOMENCLATURE

Af	Frontal Area
Cd	Drag coefficient
Cr	Rolling coefficient
CRGE	Climate Resilient Green Economy
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
ESMAP	Energy sector management Assistance program
EPA	Environmental protection Agency
Ew	Energy at wheels
EV	Electric Vehicle
Fa	Inertia force
Fd	Drag force
FE	Fuel Economy
Fg	Gravitational force
Fr	Rolling force
Fw	Force at wheels
ICEV	Internal combustion engine vehicle
ISO	International standard organization
GHG	Greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
GHI	Global Horizontal Irradiance
GW	Giga Watt
HEVs	Hybrid Electric vehicles
KWh	Kilowatt-hour
LCA	Life cycle Assessment
LCC	Life cycle cost
Mv	Mass of Vehicle
Mr	Rotational inertia
MPG	Mile per gallon
MPPT	Maximum power point tracking
New-loc-clim	New local climate
Nissan	Neatly installed sheet around nothing
RETScreen	Renewable energy technical screen
ROI	Return on investment
STC	Standard temperature condition
SRT	Standard Reporting Condition
SOC	State of Charging
SPD	Specific Power Density
TTW	Tank to Wheels
PW	Power at the Wheels

PVGIS	Photovoltaic Geographical Information System
PHEVs	Plug-In Hybrid Electric Vehicles
PV	Photovoltaic
PV watt	Photovoltaic in watt
V	Voltage
VIPV	Vehicle integrated photovoltaic
W	Watt
WTT	Well to tank
WTW	Well-to-wheels

1. INTRODUCTION

Now a day's World, energy has crucial importance for all countries. Vehicle integrated photovoltaic (VIPV) has shown the potential to fulfill the dream of free traveling since the first solar car race (Heinrich et al., 2020). The most important energy problem is energy efficiency (Berjoza & Misjuro, 2014). Since the introduction of modern technologies that have revolutionized how vehicles are built and constructed, the automotive industry has been undergoing a sea of change. Automobile firms are now focusing heavily on the impact of solar-powered automobiles. Companies are now focusing extensively on the impact of cars that run on fossil fuels, and are moving towards renewable energy.

The quests for a constant, clean, environmental-friendly fuel are never-ending. Carbon-based fuels, such as fossil fuels are unsustainable and hazardous to our environment. This thesis is focused on renewable energy, life cycle assessment of vehicle integrated solar energy on Photovoltaic (PV) technologies, in which solar energy is captured and converted to direct current electricity, have also been developed because of the availability of resources to create such technologies and because of the free nature and zero cost of solar energy (Abdelhamid et al., 2014). Photovoltaic production becomes double every two years, increasing by an average of 48 percent each year since 2002(Sharif, 2010). Due to its innumerable benefits in environmental, economic, and social aspects, PV systems have become. The world's fastest-growing energy technology. Solar photovoltaic is a promising technology for managing the onboard power systems of Hybrid Electric (HEVs) and Plug-In Hybrid Electric Vehicles (PHEVs) (Abdelhamid, 2014). With the rapid increase of Electric Vehicle (EV) production, interest in car-roof PV is increasing. With this car-roof PV, 70 % of passengers may be able to run by solar energy (Masuda et al., 2017). It is said that the potential of the market size is 50 GW/year (Araki et al., 2018). However, it is a difficult task to fill the requirement of the main component of electric vehicles and the creation of a massive market. It is also apparent that the market will be small as far as we only try to apply the conventional crystalline Si cells(Araki et al., 2019).

Why is there a recent vehicle integrated to photovoltaic is increased? Because the amount of power that can be generated on a car roof has increased significantly as solar cell and module technology has improved, resulting in greater efficiency modules. As a result, the solar roof might provide not just cooling for the passenger compartment, but also a significant increase in the driving distance. Secondly, the cost of solar cells has declined substantially in recent years, particularly in the last

10-15 years, lowering the cost of a solar car roof. Third, the market share of hybrid or completely electric cars, in which solar energy is directly used for propulsion, has exploded in recent years, with the International Energy Agency (IEA) projecting that 44 million electric vehicles will be on the road by 2030. (Heinrich et al., 2020).

Well –to- wheel analyses are divided into two stages: the fuel production is studied in the well-to-tank stage, and the vehicle operation is analyzed in the tank-to-wheel (TTW) stage. WTW neglects vehicle production and disposal, which are captures in automotive LCA studies (Orsi et al., 2016).

Africa has abundant renewable energy resources. Traditionally reliant on hydropower, the continent is moving to solar photovoltaic (PV) to improve energy security and sustainably promote rapid economic growth. Solar PV now offers a speedy, cost-effective alternative to provide utility-scale electricity for the grid and contemporary energy services to the over 600 million Africans who do not have access to electricity, thanks to recent significant cost reductions. (Irena, 2016).

As Ethiopia is transforming greening & climate resilient aspirations into concrete actions through the green legacy initiative, in July 2020, the prime minister received the first electric car fully assembled in Ethiopia. No emission cars can help reduce pollution. "Once fully charged, the electric car can go for 300 kilometers''. The plant, which opened in March, can produce 10,000 cars a year (*Ethiopia Unveils Locally Assembled Electric Cars_ Freight News*, March.2020.).

Clean and renewable hydropower dominates Ethiopia's energy generation mix, contributing around 90% of the installed generation capacity. The electricity tariffs are also very favorable, with residential tariffs at around $0.06/kWh. A study by African EV reveals just how good driving the Nissan Leaf EV and several others can be in Ethiopia (Kuhudzai, 2020).

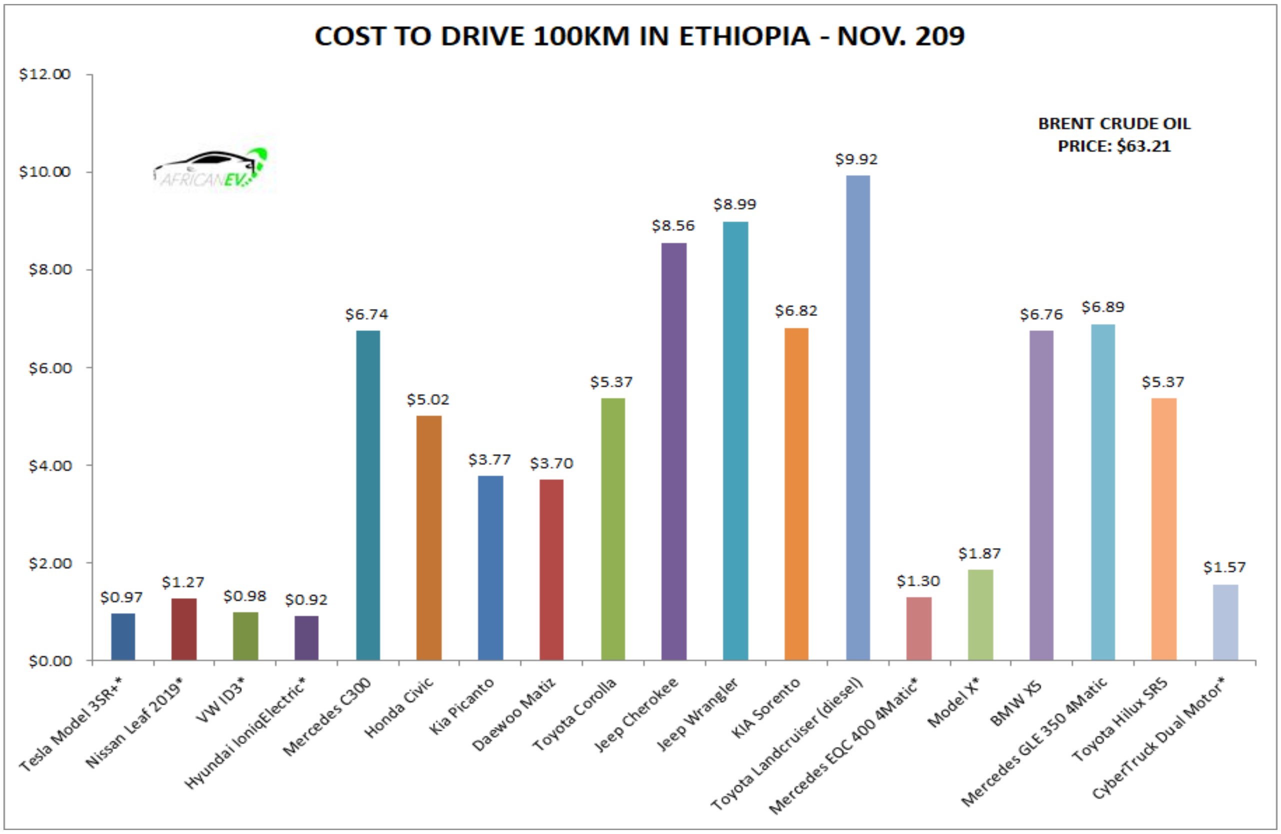


Figure 1-1.Cost to drive 100 km in Ethiopia with different(Kuhudzai, 2020)

It costs just $1.27 to drive the Nissan leaf 2019 over a 100 km trip in Ethiopia, whereas the same trip in a Toyota land cruiser highest costs you $9.92.(Kuhudzai, 2020)

1.1 Problem statement

Electric vehicles and vehicles integrated into solar energy in today's world are leading with a special controlling mechanism that is easily operated for everyone. Even though they are vital and they do have better control mechanisms, still in our country Ethiopia there is a shortage of electric vehicles and integrated solar energy. The Energy and transportation sectors face the following challenges from different aspects of Ethiopia.

1. **Energy demand in the transportation sector in Ethiopia**

Ethiopia is one of the least developed countries in the world. Approximately 34% of it is over 100 million inhabitants' line below the poverty line("Hum. Dev. Rep. 2015," 2016). It has one the lowest rate of access to modern energy services, whereby the energy supply is primarily based on biomass. Energy consumption in Ethiopia by transportation is more fossil fuel that is transported from a foreign country. This has an impact on economic and environmental pollution, therefore, make a solution for this problem should be integrated renewable energy for the creation of vehicles that use alternative fuel sources such as electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs). Photovoltaic (PV) technologies, which capture and convert solar energy to direct current electricity, have also been developed due to the availability of resources for such technologies, as well as the ubiquitous nature and zero cost of solar energy. Ethiopia is endowed with a renewable energy source. Ethiopia receives solar radiation of 500-700 Wh/m^2 according to region and season and thus has great potential for the use of solar energy. The solar radiation is uniform at around 5.2 KWh/m^2/day. The value varies seasonally from 4.55-5.55 KWh/m^2/day(Elmer & Brix, 2014).

2. Environmental and Economic issues

According to Ethiopia's Climate Resilient Green Economy Strategy, annual growth in road passenger kilometers traveled in Ethiopia is expected to range from 8.3% to 9.1%, and total passenger-kilometers traveled in Ethiopia is expected to rise from 40 billion in 2010 to 220 billion in 2030, owing to strong urbanization. (https://www.ccacoalition.org/en/content/about)

To fill those gaps to evaluate the potential power generated for vehicles, how much money can be saved when compared to gasoline, and what contribution photovoltaic integrated into vehicles can make to reduce environmental impact.

1.2 Research Question

1. Which PV module type is the most appropriate for the car rooftop vehicle application? How can we evaluate and select the best PV module?
2. What are the factors that influence the reliability and performance of the PV module?
3. How much contribution does vehicle integrate photovoltaic make toward supply energy?
4. What are the life cycle environmental impacts of the light-duty vehicle?
5. How green is the solar vehicle and is it a cost-effective solution to add a PV on the car rooftop?

1.3 Approach

The proposed approach of this thesis is to develop a life cycle assessment on PV integrated light-duty vehicles to answer the research question from one to five. Figure 1.2 highlight the thesis.

Life cycle assessment of photovoltaic integrated light-duty vehicle (well to wheel) analysis.

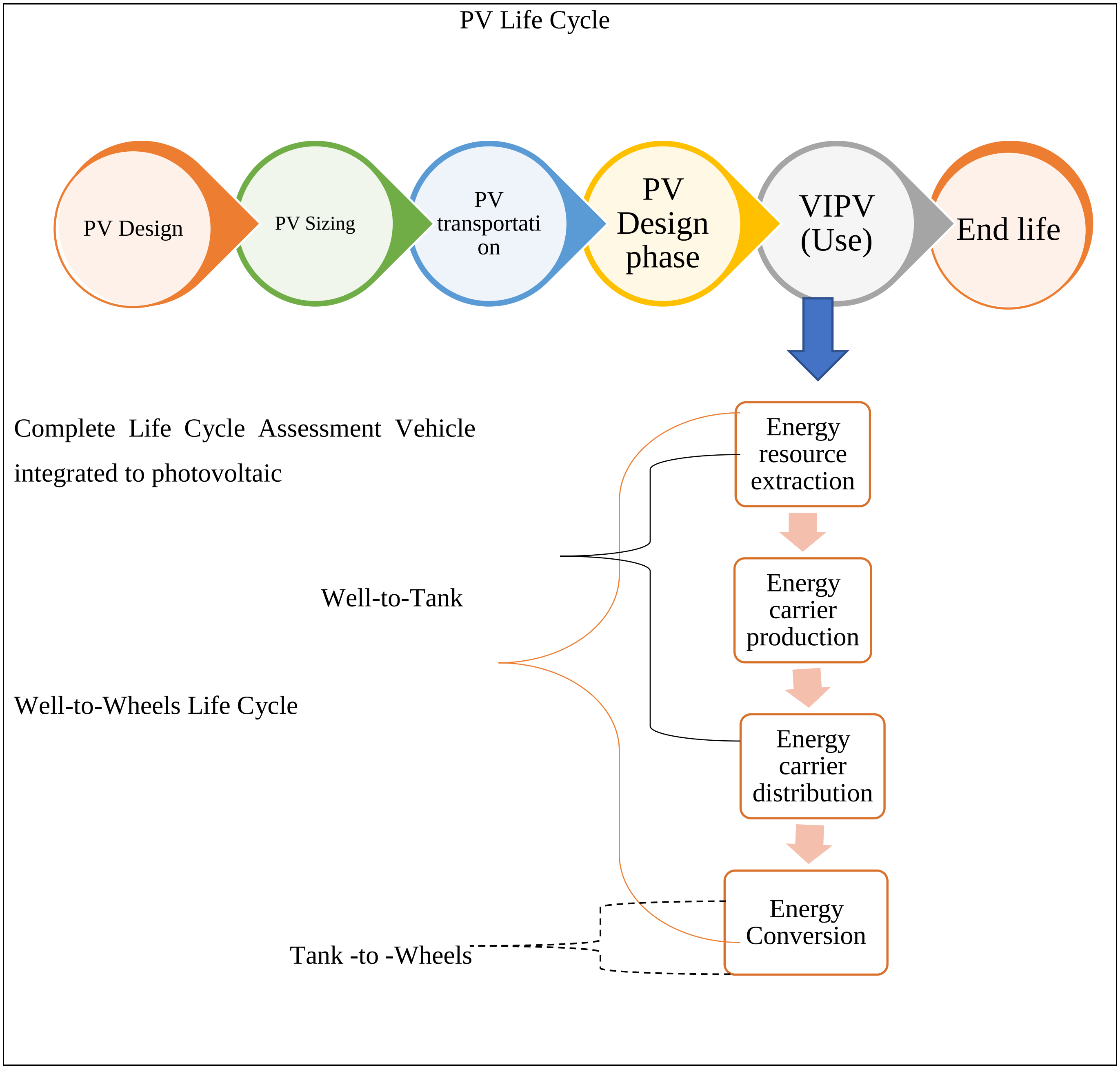


Figure 1-2.Life cycle assessment of Vehicle integrated to PV

1.4 Scope of the Study

The life cycle assessment of photovoltaics on light-duty vehicles is vast. Therefore, the focus of this study is only on wheels due to the budget and shortage of time. This paper focuses on the selection of type PV for the electric vehicle based on the functional requirements of PV and the life cycle assessment of photovoltaic panels. In addition, well to wheels will be studied and can be used as a tool to evaluate and compare the energy consumption, economic cost, and environmental impact of different passenger vehicles. Well-to-wheels analyses are divided into two stages: the fuel production is studied in the well-to-tank (WTT) stage, and the vehicle operation is analyzed in the tank-to-wheel (TTW) stage.

1.5 The Objective of the Study

1.5.1 General Objective

The objective of this study is to investigate the life cycle assessment of photovoltaic light-duty vehicles, developing a suitable energy forecast of a roof and side-mounted to judge the integrated economic and environmental impact of a VIPV system.

1.5.2 Specific objective

1. To determine gasoline energy equivalent substituted by PV solar increased mileage
2. To determine the cost saved for charging electricity and the reduction of CO2 emissions due to the proposed intervention.
3. To compare LCA (well-to-mile analysis) of gasoline vehicles with and without on-rooftop car PVs with respect to environmental and economic analysis.
4. To compare LCA (well-to-mile analysis) of a plug-in electric vehicle with and without on-rooftop car PVs with respect to environmental and economic analysis.

1.6 Research Gap

Solargis, Bluesol, PVwatt, PVGIS, PV*sol, and GREET are examples of modern PV system simulation tools, but they cannot calculate the yield of a moving PV installation. Many researchers have investigated energy production and computed the quantity of carbon dioxide reduction and environmental impact without taking into account the shadow factor, sky clarity, and temperature effects. Using PV*Sol and other tools, this work intends to fill this gap and develop a PV application with 2D/3D visualization and detailed shading analysis of solar and storage systems. This study addresses the subject of how much vehicle-integrated PV can replace gasoline as an energy source, as well as the project's potential for addressing climate change.

2. LITERATURE REVIEW

2.1 Life cycle Assessment

All things have a duration of life or a life cycle of “birth”, “use/service” and “death” which influence their environment.

Life cycle assessment (LCA) is a way for quantifying the impact of the environmental and human health impacts of a product over its duration of life other name life cycle analysis, life cycle approach, and cradle -to grave analysis, eco-balance, or environmental foot printing (Patterson & Johnson, 2018).

Life Cycle Thinking is a method of thinking that involves the social, environmental, and economic consequences of a product or process over the entire life cycle. LCA is a technique for evaluating the environmental aspects and potential impacts of a product, process, or service by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential environmental impacts associated with identified inputs and releases, and interpreting the results to assist you in making a more informed decision.” (Patterson & Johnson, 2018).

“It is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment. The evaluation covers the whole life cycle of a product, process, or activity, including raw material extraction and processing, manufacture, transportation, and distribution; usage, re-use, and maintenance; recycling, and final disposal. (Patterson & Johnson, 2018)”

2.2 LCA Studies of Photovoltaic Panel

Many researchers began researching photovoltaic panel life cycles, energy consumption, and environmental impacts, and contribution to carbon emission reduction starting in the mid-1970s. Life cycle assessment of the energy consumption and environmental effects of PV systems has gradually increased. Silicon is the second most abundant element in the Earth's crust, compromising approximately 26% of it. Silicon does not exist naturally in its elemental form, but as silicon dioxide (SiO_2) in sand, rock, and quartz. The silicon dioxide must be converted to elemental silicon (Si), with very low levels of contaminants to be useful in PV applications (Ludin, 2019).

The silicon manufacturing method plays a big role in differentiating them into metallurgical-grade silicon (MG-Si), then into electronic silicon (EG-Si) through the Siemen's processor into solar-grade silicon (SoG-Si) through the modified Siemens process. The first step in this purification process is to produce metallurgical grade silicon (MG-Si). A purity of 98-99% silicon for the MG-Si is not pure enough for solar cell application. The MG-Si has to be further purified to reach a high purity of 99.9999% (six nines pure). Silicon with this purity is called solar grade silicon (SoG-Si). Most of the MG-Si is commercially produced by carbothermic reduction of silicon dioxide(Ludin, 2019).

2.3 Type and selection criteria of PV

The PV technologies are classified into three generations of the cell 1st generation Silicon cells are Monocrystalline silicon cells (mc-Si), Polycrystalline silicon cells (poly-Si), and EFG ribbon silicon(c-Si) 2nd generation Silicon cells are Amorphous silicon cells(a-Si), Multi-junction (a-Si/µ-Si), Cadmium telluride (CdTe), and copper indium gallium selenide (CIGS) 3rd generation (Emerging and novel PV technologies) are Concentrating PV (CIS), Organic solar cells, Advanced inorganic thin films, Novel and emerging solar cell concepts, Multiple solar cells, and Black silicon(Giorgio, 2013).

Table 2-1.Criteria selection of type PV panels

	Criteria selection PV					
PV type	Power density(w/m^2)	Specific weight (w/kg)	Efficiency (%)	PTC/^{O}C	Cost/$/KWh	Material
mc-Si	184	14.4	15-18	0.411	1.853	Excellent
Pc-Sci	139	12.2	14-15	0.437	1.871	Excellent
a-Si	63.7	4.1	6.35	0.226	1.660	Excellent
a-Si/µ-Si	92.8	5.9	9.30	0.263	1.650	Excellent
CdTe	107.9	6.3	10.80	0.250	1.652	Least
CIGS	125.4	7.5	12.5	0.355	1.769	Moderate

Source(Abdelhamid et al., 2014).

According to the author said that 'based on Table: 2.1 Calculation of life cycle cost (LCC) of electricity indicator for comparison since the constraint here is the installation surface area on the vehicle. The LCC is defined as the total cost of PV system per total energy generated through the PV system in the life cycle in the unit ($/kWh)’. The LCC is calculated.

$$LCC(\$/KWh) = \frac{Cost \sum [PV\ module + Installation + Land + Energy\ storage\ maintenance]}{Total\ energy\ generated} \quad \text{--} \quad 2.1$$

Source(Abdelhamid et al., 2014).

Table 2-2. LCC of electricity of different PV module options

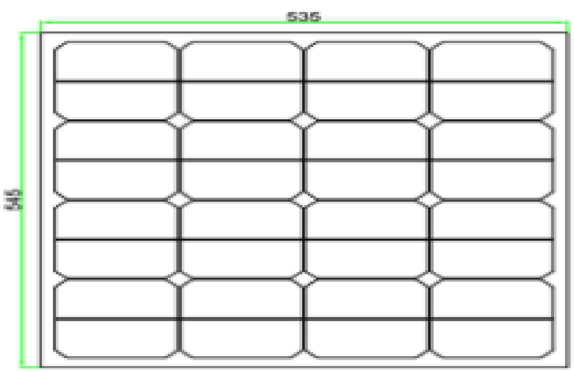
	PV type					
Criteria	mc-Si	Pc-Sci	a-Si	a-Si/µ-Si	CdTe	CIGS
PV module price ($/w) include tax	0.655	0.655	0.583	0.583	0.583	0.583
PV module price ($/w) (with sales tax=7%)	0.701	0.701	0.624	0.624	0.624	0.624
Cost PV module ($/m^2)	117.392	105.198	39.737	57.890	67.309	78.226
PV module Average life time efficiency (%)	15.640	13.880	5.90	8.661	10.60	10.920
Total energy generated (KWh)	6334.20	5621.400	2393.55	3507.826	4074.3	4422.60
Cost PV per total energy generated ($/KWh)	1.871	1.853	1.660	1.650	1.652	1.769

Source (Abdelhamid, 2014).

Selection is based on assessing PV modules for commercial use in EVs. There are several PV functional requirements, such as power density, specific weight, and efficiency, life cycle cost for electricity, power temperature coefficient, and material concern. Since solar cars have much less energy to work with to drive the car compared to say energy provided by internal combustion engines, this small energy must be as efficiently utilized as possible. In addition, the lesser space the solar panels take up over the body of the car the better it is. Therefore, judging from the characteristics of the several types of solar panels as described above it was most prudent to go with the monocrystalline type of solar panels. Considering solar panel cost, durability, longevity, warranty, and size, and wattage, five monocrystalline flexible solar panels. It is very important to note that each of the panels was semi-flexible which allowed the roof of the car (where the panels are to be placed) to have a more curved and aerodynamic shape rather than being flat (Abdelhamid et al., 2014)

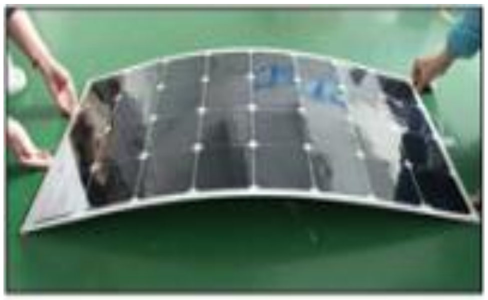
Table 2-3. Specification and rating of monocrystalline PV module

50-Watt monocrystalline bendable photovoltaic module.		
Electric characteristics		
Max power	P max	50W
Max power voltage	Vmp	17.6 V
Max power current	Imp	2.84 A
Open circuit voltage	VOC	21.2v
Short circuit current	Isc	3.05A
Max systems voltage		600v
Series fuse rating		10A
Temperature coefficient		
Power = -0.38%/ ^{o}c Voltage = -60.8 mA/ ^{o}c Current = 2.2mA/ ^{o}c		
Cell efficiency		21.5%
Number cells in series		32
Max power tolerance		$\pm$5
Mechanical characteristics		
Weight		0.7kg
Dimension		545*535*3



Dimension of PV

Figure 2-1.specification and rating used PV



The maximum recommended bending degree is 30^{o}

Source(Abdelhamid et al., 2014).

2.4 Module Sizing for vehicle integrated PV

Two PV system configurations are considered in this paper: one where modules are mounted on-board include of only on the roof and side of the vehicle, and another where modules are mounted on the off-board (grid-in) of the vehicle as well. The sizing of the modules on the roof and each of the sides is determined based on vehicle parameters. The size of the PV module is calculated from the vehicle geometry and is used to estimate the rating of the roof and side PV system. The vehicle has small size and large size are take approximately, as a box that is used for PV are height, width and mm length respectively. To maximize the impact of onboard PV, all possible surfaces should be exploited. It is estimated that the roof-mounted panels, used by both configurations, can cover 60% of the bus roof area *a top*. The right and left side modules each cover the same area of their respective sides and are estimated to cover 40% of the side area *A*-side. These areas are denoted A_{pv}, top, A_{pv}, right Apv left respectively and Apv, back, is neglect because small in size and not comfortable for onboard PV.

Source (*Tina Casey,2018*).

Figure 2-2.on-board vehicle integrated PV

$$A_{PV\ top} = 60\%\ x\ A_{top} \tag{2.2}$$

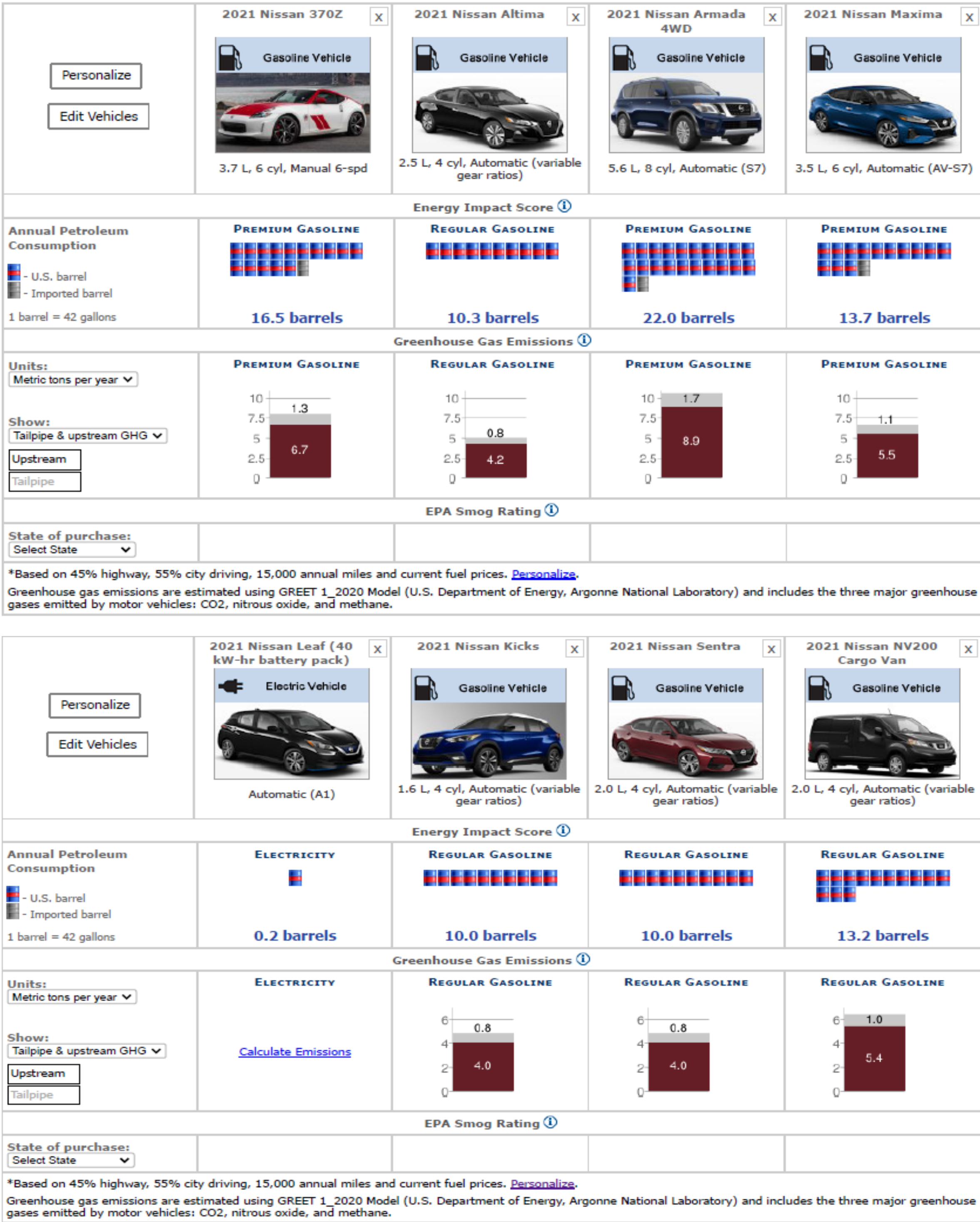
$$A_{PV\ right} = 40\%\ x\ A_{side} \tag{2.3}$$

$$A_{PV\ left} = 40\%\ x\ A_{side} \tag{2.4}$$

The SRC is the laboratory test condition under which commercial and research PV modules are rated. This produces the rated power, Prated, of the module under SRC as described in the equation. To avoid redundant equations, the vehicle surface is indexed by subscript j with j=top, right and left referring to each surface of the vehicle, Then:

$$P_{rated}, j = A_{pv}, j \times SPD \tag{2.5}$$

$$M_{PV}j = A_{pv}, i \times AD \tag{2.6}$$



Source (*Compare Side-by-Side*, 2021) (https://www.fueleconomy.gov/)

Figure 2-3.Energy and Environmental compare side-by-side vehicle

2.5 Electric Vehicles Powered by Photovoltaic Modules

Here, we estimation is the potential driving ranges for EV powered only by PV modules based on the mono-Si PV option, which was ranked first in the study. The proposed EV is lightweight with an efficient aerodynamic design. The first set of PV modules is assumed to cover a total surface area of $2m^2$ on the vehicle roof to charge the onboard battery. The other set is assumed to cover an area of 5 m^2, which will be used to charge batteries at home (Abdelhamid et al., 2014).

2.6 Well- to -Tank analysis

A well-to-Tank analysis is a partial LCA, which limits its system boundary to the cycle of the energy carrier used to propel the vehicle, such as liquid fuel or electricity (Marmiroli et al., 2018).

2.6.1 Energy resource extraction

The global horizontal irradiance (GHI), which is the total incident solar radiation reaches the ground in unit kWh per m^2 for a specific period e.g., day, month, and year. The GHI reaches the ground in three ways: direct normal radiation (DNI), diffuse horizontal irradiance (DHI), and reflection. The DNI represents the solar energy that reaches the ground in a straight line from the sun. The DHI represents the amount of solar energy that does not arrive on the ground on a direct path from the sun. The DHI component is arrived after scattering or diffused by molecules and particles in the atmosphere(Abdelhamid, 2014).

The screening methodology predefined vehicle operation is chosen in a way that irradiance, climatic conditions, and diesel prices were used for the analysis. Among other factors, the savings in cost and CO_2 depend on the amount of electricity produced by the VIPV system. As the amount of PV-generated, electric energy is proportional to both the amount of time the vehicle is exposed to sunlight and the available surface area, for my study only commercial vehicles (Kronthaler et al., 2014). Considering the efficiencies of the alternator plus ICE, a considerable amount of fuel could be saved over the lifetime of a vehicle by providing an additional electric energy source, such as a VIPV system (Kronthaler et al., 2014).

2.6.2Vehicle and Energy source

An electric vehicle is defined as any vehicle that gets some or all of its driving energy from a battery. A conventional internal combustion engine vehicle (ICEV) uses gasoline or diesel fuel to generate mechanical energy, which is used to propel the vehicle forward. Several electric vehicle (EV) technologies are either in use or in being developed. A hybrid electric vehicle (HEV) features a tiny electric battery that provides power to the drivetrain, allowing the combustion engine to run more efficiently. The battery in an HEV can be charged by the engine or by regenerative braking, which captures kinetic braking energy. Although HEVs are more fuel-efficient than ICEVs, they are still powered entirely by liquid fuel. The concept of a plug-in hybrid electric vehicle (PHEV) is similar to that of a hybrid electric vehicle (HEV), but with a larger battery and a grid connection. The grid connection allows the battery to be charged with energy, and the car's larger battery capacity allows it to travel a long distance in all-electric mode. The designation PHEV-20 denotes a twenty-mile all-electric range, whereas PHEV-40 denotes a forty-mile all-electric range. A battery electric vehicle (BEV) is a vehicle that runs entirely on grid electricity and is fueled by a massive onboard battery. EVs use energy far more efficiently than ICEVs; a standard ICEV's fuel efficiency is 15–18%, whereas a BEV's efficiency can reach 60–70%. (Richardson, 2013).

2.6.3 Charging and grid connections

Charge plans are used to describe how an electric vehicle's battery can be recharged from the grid with varying degrees of external management. A simple charge plan, also known as an unconstrained charge plan, is one in which the vehicle begins recharging as soon as it is connected to the grid. A delayed charge plan defers battery charging for a specified period, such as three hours (Richardson, 2013). Charges are deferred until later in the night, when electricity prices are lowest, leaving the battery fully charged for use in the morning. Smart charging is based on the principle of charging the car when it is most advantageous, which could be when electricity is at its cheapest, demand is at its lowest, there is excess capacity, or depending on some other parameter. The charge rate can be adjusted within specific parameters established by the driver; the most fundamental need is that the vehicle be fully charged before morning. Some argue that managing battery performance and longevity should be one of the main goals of smart charging, as this can improve the battery's lifetime economics (Richardson, 2013).

2.6.4 Vehicle-to-Grid

A vehicle-to-grid (V2G) capable EV can store electricity and then return it to the electric grid. V2G power is an interesting concept that was first proposed by(Prevedouros & Mitropoulos, 2016). The authors suggested that V2G could be used to generate a profit for vehicle owners if the power was used under certain conditions to provide valuable services to the electric grid(Richardson, 2013).

2.7 Tank to wheels analysis

2.7.1 Energy conversion system

The efficiency of energy conversion from fuel to electricity is estimated to be about 21% but varies with engine and alternator efficiencies, engine speed, and energy-storage-device (e.g., battery) state of charge (SOC). When there is no electrical load and the energy-storage device is at full SOC, the alternator operates at low efficiency, with its mechanical energy dissipated as heat. The inefficiency of the alternator under these conditions increases with increasing engine speed due to the increase in alternator capacity with engine speed (Negroni & Aldredge, 2013).

Vehicle integrated photovoltaic (VIPV) electricity can reduce peak alternator load requirements, power electrical loads directly, or charge energy storage devices for later consumption. Most VIPV applications focus on enhanced propulsion or extended battery range for battery-electric vehicles, or reductions in auxiliary loads of optional air conditioning systems in hybrid-electric vehicles. VIPV charging, as a complement to alternator charging, can help increase battery longevity and performance by topping-charge enhancement during normal operation and as a float charge during non-operation (Negroni & Aldredge, 2013).

2.8. Well to Wheels analysis

Well-to-wheel studies can be used as a tool to evaluate and compare the energy consumption, economic cost, and environmental impact of different passenger vehicles. The comparison is based on three indicators: (1) primary energy consumption, with particular focus on the ability to displace oil by different personal transportation technologies; (2) CO2 emissions; and (3) economic cost (Orsi et al., 2016).

Many variations of WTW studies have been proposed in the literature to capture different aspects of the fuel life-cycle of transportation fuels in different regions of the world. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) fuel-cycle model developed by the U.S. Argonne National Laboratory is currently the most widely adopted software to perform WTW studies. Developed in 1996, the model has been constantly updated and has been adopted in several studies. (Orsi et al., 2016).

3. MATERIALS AND METHODS

3.1 Materials Used

To achieve the objectives of this work, generally, the following extra materials are used in this study by integrating them into each other according to their importance:

Solargis: - develops and operates a platform for fast access to historical, recent, and forecast data for almost any location on the Earth.

Bluesol: - is software for the design of photovoltaic systems in every country in the world.

PVwatt: - Calculates the energy production and cost of energy for grid and off-grid photovoltaic (PV) energy installations all over the world.

New- LocClim: - is a freeware tool to estimate local climatic conditions for any location

PVGIS: - to evaluate PV potential estimation utility in monthly and daily radiation including mapping.

A **driving cycle**: - is a speed-time profile designed to represent a real-world driving pattern

PV*sol: - to simulate PV program with 2D/3D visualization and detailed shading analysis of photovoltaic system and storage system

GREET: To model estimates the full fuel cycle energy use and greenhouse gases (GHG) emissions associated with various transportation fuels for light-duty vehicles.

3.2. Life Cycle Assessment (Well to Tank) of Vehicle Integrated to PV

3.2.1. Solar Resource Maps of Ethiopia

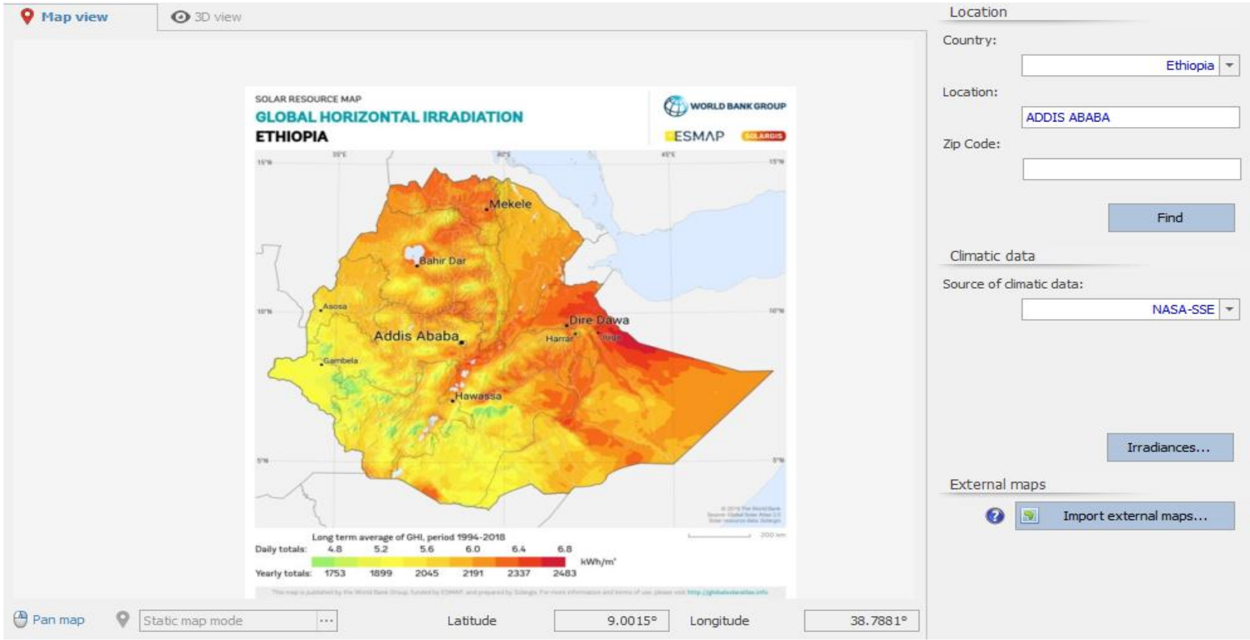
The maps and data for Ethiopia were released in tandem with the World Bank Group's worldwide solar atlas, which was financed by ESMAP and developed by solargis. The World Bank, with the necessary and binding addition that they are presented in global solar atlas terms, licenses all maps on this page under the Creative Commons Attribution License (CCBY4.0). (Source: The World Bank, 2019).

I start with an analysis of currently available electric vehicles and compare the largest available battery size of each series, the consumption, and the respective range. I have collected data on the roof area and side areas of vehicles for equipment with solar cells for two reasons:

Firstly, the roof and sides provide a rather simple technological implementation; the curvature is quite low, glass roofs with a similar layout, such as solar roofs, are already available and manufacture has already produced and sold solar roofs. Secondly, the yield on the car roof is potentially the highest relative to other surfaces of the car, since the area is quite large, the orientation of the roof is favorable, and due to low curvature, the mismatch between cells may not be significant. Data were collected from Solaris, Bluesol, PVwatt, new-locClim, RETScreen and drive cycle software which are weather data such as temperature and wind speed, solar data (in terms of GHI, DHI, and DNI,), and geographical data included latitude and longitude are the input of data for this research thesis.

3.2.2. Global Horizontal Irradiation (GHI)

GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies. This solar resource map provides a summary of the estimated solar energy available for power generation and other energy applications. It represents the long-term average yearly/daily sum of global horizontal irradiation (GHI). The underlying solar resource database is calculated by the Solargis model from atmospheric and satellite data with a 10, 15, or 30-minute time step (depending on the region). The effects of terrain is considered at the nominal spatial resolution of 250 m.



Source (Group World Bank, 2021)

Figure 3-1. Global horizontal Irradiation of Ethiopia.

Ethiopia is a country in the Horn of *Africa*. The country lies completely within the tropical latitudes and is relatively compact, with similar north-south and east-west dimensions (World Bank, 2019). The yearly GHI of the Ethiopian solar map is shown in Figure 3.1. The highest solar energy in Ethiopia is located in the eastern and north, where the GHI is greater than 2045 kWh/m^2/year and could reach more than 2222.85 kWh/m^2/year. This means the daily global solar is roughly between 5 and 6.8 kWh/m^2 in these areas (see Figure 3.1).

GHI data were collected by using different software. Based on those software solargis and PV watt are correct to compare to others.

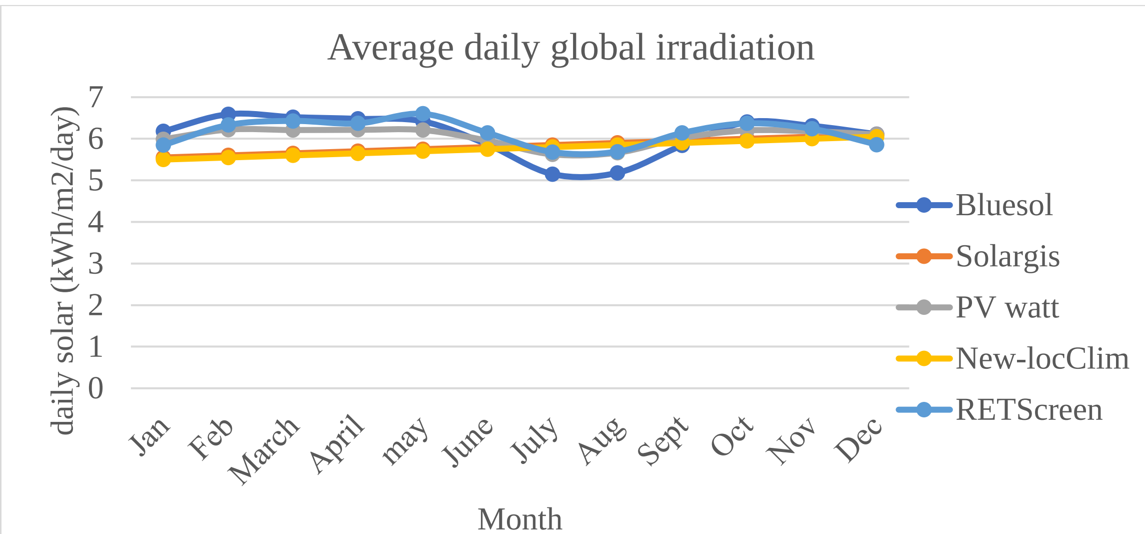
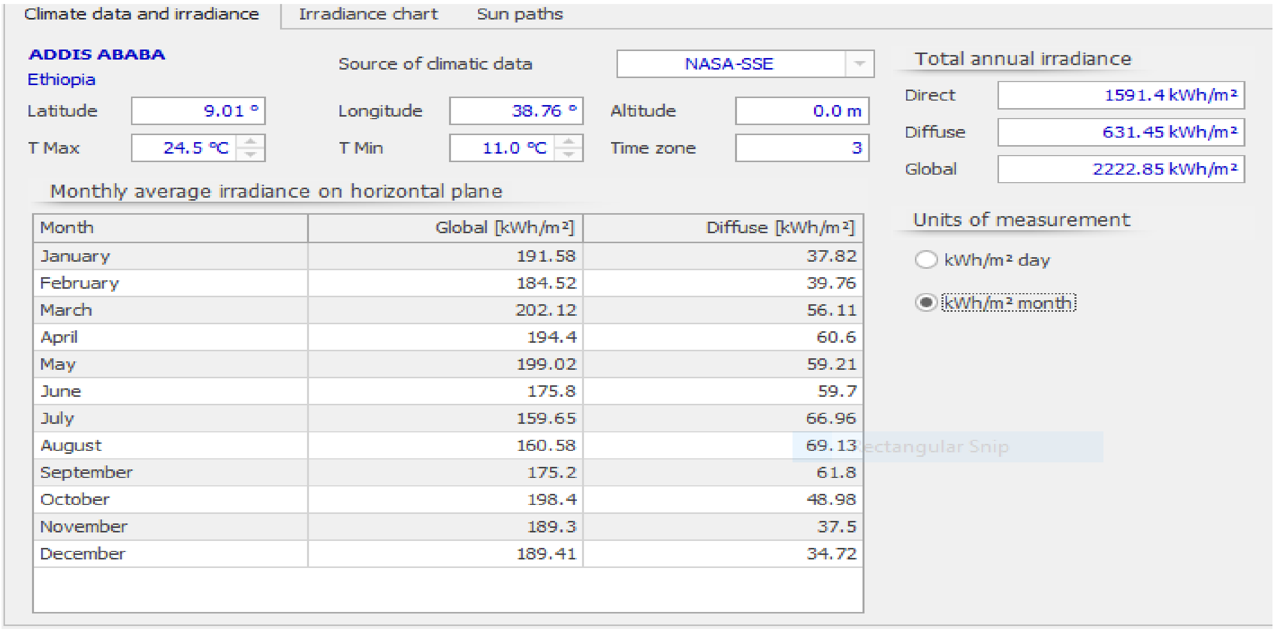


Figure 3-2.Average daily global Irradiation for different software.

3.2.3. Direct Normal Irradiation (DNI)

The DNI is the most essential metric for calculating energy yields and evaluating the performance of concentrating solar power (CSP) and concentrator solar photovoltaic (CPV) systems. DNI is also crucial for calculating the global irradiation received by photovoltaic modules that are inclined or sun tracking. This map of solar resources summarizes the estimated solar energy available for power generation. It represents the long-term average yearly/daily sum of direct normal irradiation (DNI).

Figure 3.3 shows the analysis of the gathered climate data, total annual irradiance, and monthly average irradiance on the horizontal plane.



Month	Global [kWh/m²]	Diffuse [kWh/m²]
January	191.58	37.82
February	184.52	39.76
March	202.12	56.11
April	194.4	60.6
May	199.02	59.21
June	175.8	59.7
July	159.65	66.96
August	160.58	69.13
September	175.2	61.8
October	198.4	48.98
November	189.3	37.5
December	189.41	34.72

Source (http://www.bluesol/ethiopia)

Figure 3-1. Climate data and irradiance

Yearly two months were selected to determined Minimum and Maximum power generation monthly and daily, the average daily GHI was collected using weather data. The highest and lowest average daily GHI in February and July are occurring as 6.59 kWh/m^2 and 5.15 kWh/m^2 respectively, as expected, per month there are differences in solar data per location in Ethiopia. Considering the monthly daily irradiation average and the number of days, which make up the 12 months of the year, you can determine the value of annual global irradiation on a horizontal surface for the location of Ethiopia. Daily average Irradiance on the horizontal plane value is equal to 6.09kWh/m² shown in Table 3.1

Table 3-1. Daily average Irradiance on the horizontal plane

Month	No of days	Global(kWh/m2)	Direct(kWh/m2)	Diffuse(kWh/m2)
January	31	6.18	4.96	1.22
February	28	6.59	5.17	1.42
March	31	6.52	4.71	1.81
April	30	6.48	4.46	2.02
May	31	6.42	4.51	1.91
June	30	5.86	3.87	1.99
July	31	5.15	2.99	2.16
August	31	5.18	2.95	2.23
September	30	5.84	3.78	2.06
October	31	6.4	4.82	1.58
November	30	6.31	5.06	1.25
December	31	6.11	4.99	1.12
Total		6.09	4.36	1.73

The GHI is determined based on equation (3.1), which is the summation of DHI and the cosine (θ) component of DNI. The "θ" see figure 3.4 is the angle of incidence, which is computed as the angle between the direct normal radiation on the surface and the normal to that surface.

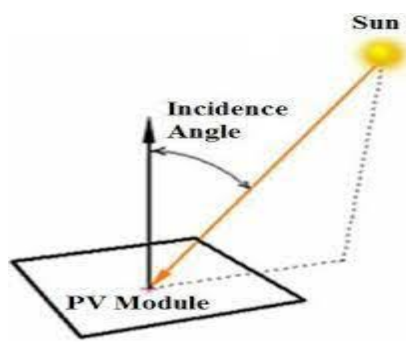


Figure 3-2.angle of incidence

$$GHI = DHI + DNI * \cos(\theta) \quad 3.1$$

The cos θ is approximate by using the equations 3.2 and 3.3 below (Deceased & Beckman, 1982).

$$\cos(\theta) = \sin(\delta)\sin(\emptyset)\cos(\beta) - \sin(\delta)\cos(\emptyset)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\emptyset)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\emptyset)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega) \quad 3.2$$

$$\delta = 23.45 \sin(360 \frac{284+n}{365}) \quad 3.3$$

Were,

∅: Latitude, the angular location north or south of the equator, north positive

δ: Declination, the angular position of the sun at solar noon. (See figure 3.5 detail)

n: number of days(Berisha et al., 2017).

β: Tilt angle, the angle between the plane of the surface and the horizontal; (β = 0° means that the PV surface is horizontal), (β = 90° means that the PV surface is vertical), and (β >90° means that the surface has downward-facing components). This applies to fixed PV and PV with a one-axis tracker. γ: Surface azimuth angle, the deviation of the projection on a horizontal plane on the normal to the surface from the local meridian, with zero due south, negative is east, positive is west. These directions may be different if the geometry assumptions are changed.

This only applies to fixed PV modules with tilt angles with no tracker option. ω: Hour angle, the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis at 15° per hour, morning is negative and afternoon positive.

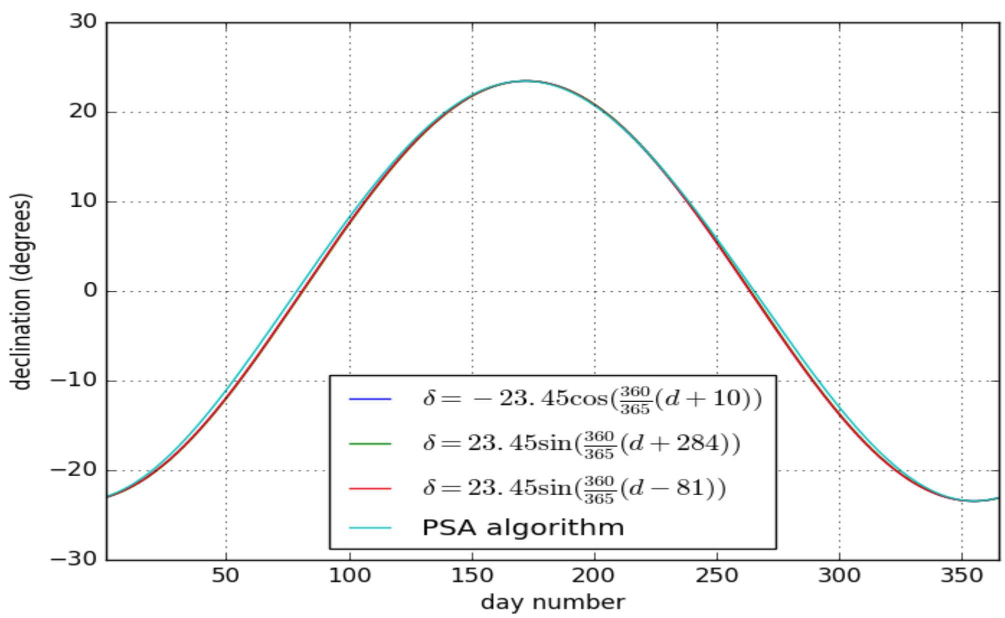


Figure 3-3.Declination angle

Table 3-2. Displayed the recommended average days for months

Month	The average day of the month	Day of year
Jan	17	17
Feb	16	47
March	16	75
April	15	105
May	15	135
June	11	162
July	17	198
Aug	16	228
Sep	15	258
Oct	15	288
Nev	14	218
Dec	10	344

Source (Khosravi et al., 2020)

Daily global irradiation solar data was different per month as shown in figure 3.6. The maximum and minimum daily global solar irradiation in Feb and July with values of 6.59 and 5.15 kWh/m^2/day respectively as shown in Table 3.1

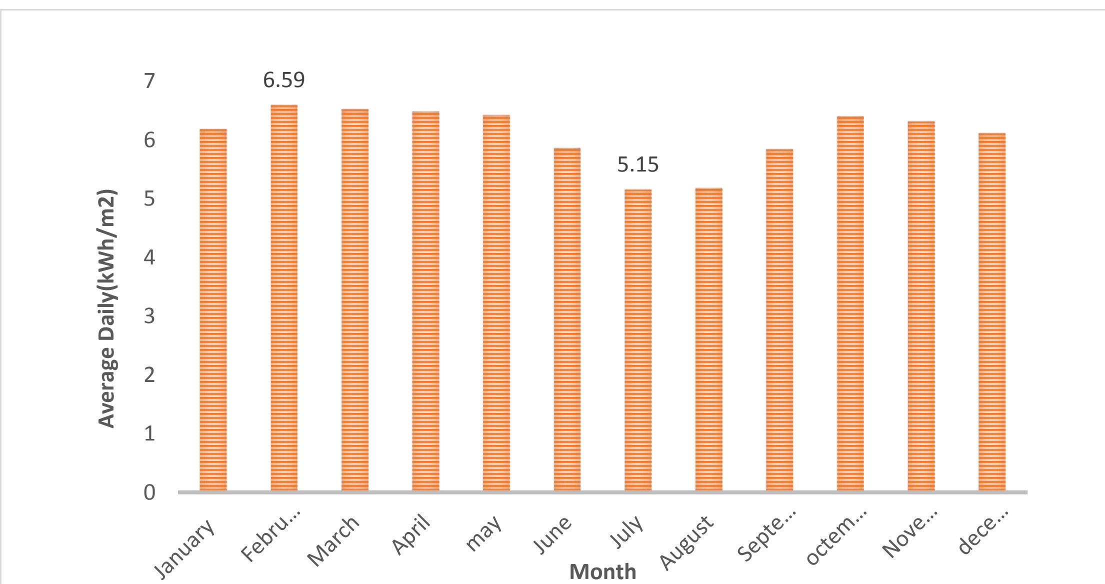


Figure 3-4. Average daily Global irradiation

In February, there is solar energy starts from 7 am increasing gradually to reach the maximum at noon, which around 812 Wh per m^2, then decreasing until the sunset around 7 pm. In July, the maximum solar energy is also at noon, but equal to less than 0.5 kWh with the availability of solar energy only from 7 am to 5 pm.

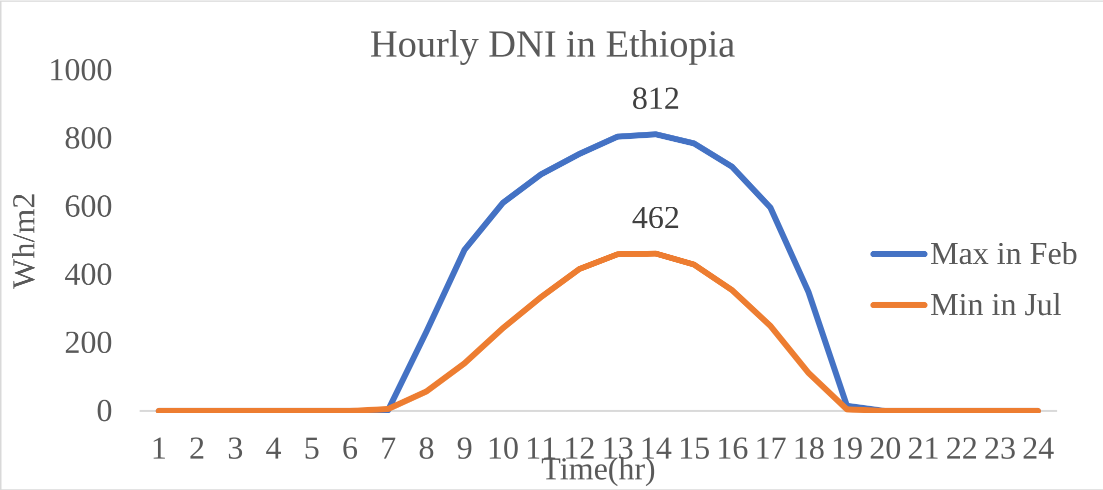


Figure 3-5. Direct normal irradiation max and min in Ethiopia

As shown in figure 3.8 hourly global irradiation solar data were per hour, here in February solar irradiation is 973 Wh/m^2 the maximum value, and the minimum value is recorded in July 774 Wh/m^2.

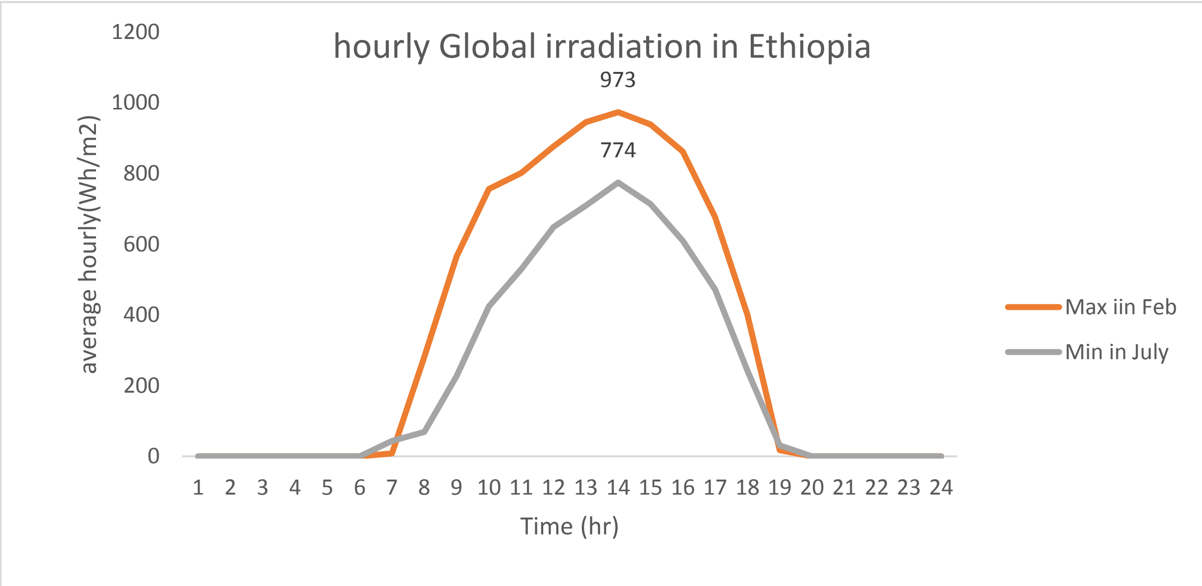


Figure3-6. Hourly global irradiation max and min in Ethiopia

3.2.4 Shadow and Sky Clearness

Alternatively, choice based on designer, if need to increase PV output current the parallel connection is used. Nevertheless, to increase PV out voltage, the series connection is used. The direct component reaches the PV module affected if there are any shadows on the PV module (e.g., shadows created by nearby buildings, large vans, trees, etc.). The DHI component could be affected and minimized based on the sky clearness, which is the factor that the sky is obstructed. Equations 3.4 &3.5 represent the GHI in both parking and driving modes.

$$GHI_{\text{parking mode}} = \vartheta_P \text{ x } DHI \cos(\theta) + \varphi_p \text{ x } DHI \quad 3.4$$

$$GHI_{\text{driving mode}} = \vartheta_d \text{ x } DHI \cos(\theta) + \varphi_d \text{ x } DHI \quad 3.5$$

Were,

ϑ, is the shadow factor varying between $0 \leq \vartheta \leq 1$

φ, is the sky clearness factor varying between $0 \leq \varphi \leq 1$

3.2.5 PV Module for vehicle selection

The now-day widespread use of photovoltaic panels, which is the sustainable, renewable, free, and clean source in a fuel-efficient electric vehicle, will ensure independence and a reduced environmental impact. Solar photovoltaic (PV) technologies can provide energy to the electric vehicle via either on-board or off-board methods. In the off-board applications, the PV is stationary mounted on a dedicated charging station or roof of a building. In the onboard applications, the PV modules are vehicle-mounted either to assist in propulsion or to run a specific vehicle application. Although the off-board (stationary) PV application is less design complex, because more installation spaces are available, fewer weight constraints and tilting options are allowed, it needs extra infrastructure as battery storage or inverter in case it supplies energy to the grid and can mainly use for vehicle prolusions applications. Sun Power Corporation model E20-327 then manufactured this paper. The mono-crystalline silicon (mono-Si) PV cell was chosen as the best option for the on-board vehicle application. Because of its high performance, outstanding durability, high efficiency, and proven value. For example, high energy production, as seen in figure 3.9 (mono-Si) E20-327 high year one performance, delivers 7-9% more energy per rated watt. This advantage increases over time, producing 20% more energy over the first 25 years of your needs.

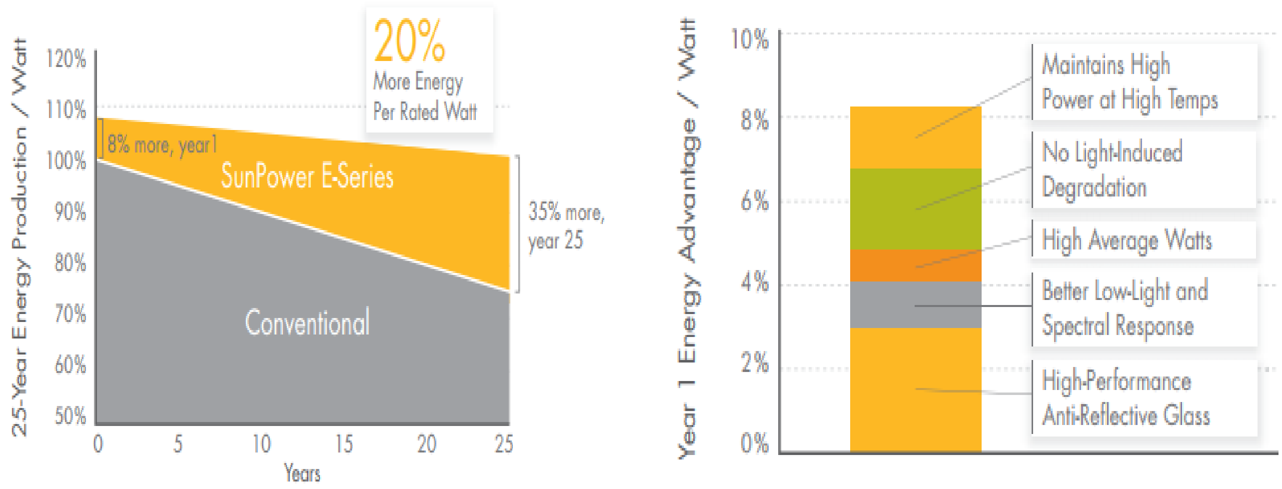


Figure 3-9. High-energy production in 1 and 25year

3.2.6. PV module electrical performance

The PV module(s) the electrical performance is described by the following parameters.

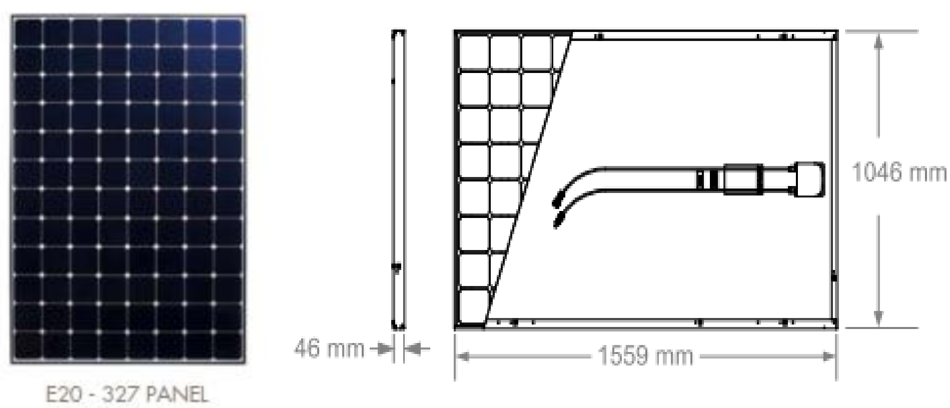


Figure 3-10. Dimension and specification of PV

Table 3-3. Properties of Mono-SiE20-327 under normal condition

Electrical data The measurements were conducted under standard test conditions (STC); irradiance of 1000w/m2, air mass of 1.5kg, and a cell temperature of 25 °c of Mono -Si E20-327		
Nominal power	**(P nom)**	327W
Tolerance		+5/-0%
Average panel efficiency	η	20.4%
Rated voltage	Vmpp	54.7V
Rated current	Impp	5.98A
open-circuit voltage	V_{OC}	64.9V
short circuit current	I_{SC}	6.46A
Max. series fuse		20A
Temperature coefficients		
	Power Temp Coef.	-0.380 %/°C
Voltage Temp Coef.		-176.6 mV/°C
Current Temp Coef.		3.5 mA/°C
Surface power density	SPD	185.20W/m2
Operating Condition and Mechanical data		
Temperature		-40-85°c
Max Load		Wind :2400 pa, 245kg/m2 frontal &back Snow :5400pa,550 kg/m2 frontal
Impact resistance		25mm diameter hail@ 23m/s
Length		1559mm
Width		1,046mm
Thickness		46mm
Area		$1.61m^2$
Weight		18.6kg
Tests and Certifications		
Quality test		**ISO 9001:2008, ISO 14001:2004**

FF= (Pmax (W))/(Isc (A)*Voc(V)) 3.6

Pmax (W)=Imp(A) *Vmp (V) 3.7

Were , FF:- fill factor

The energy conversion of PV efficiency (η) is determined as the ratio of incident power from the sun, which is converted to electricity and is defined using equation (3.7):

$$\eta\ (\%) = \frac{Pmax\ (W)*100}{1000(Wm-2)*\ cell\ Area\ (m2)} \qquad 3.8$$

Under normal conditions, the PV solar cell area in meter square and 1000 W/m^2 is the maximum solar energy that reaches the earth for terrestrial PV model application at air mass 1.5 ($AM_{1.5}$) and a temperature of 25^0c.

3.2.7. The thermal performance of a PV solar module

The meteorological data; wind speed (WS), ambient temperature (T_a), and global horizontal irradiance (GHI), is passed over to the PV simulation block. Instead of the normal wind speed, the combination of headwind of the vehicle and ambient wind speed is passed. second, the potential production of two module types is calculated, as well as the additional heat load transferred into the lorries and the benefit of a reduced cell temperature caused by the headwind.

For the calculation of cell (T_c) and module temperature (T_m), meteorological parameters (irradiance, ambient temperature, and wind) and mounting and technology depending empirical parameters (a, b, and ΔT) are needed.

$$T_m = GHI.(e^{a+b.ws}) + T_a \qquad 3.9$$

$$T_c = T_m + \frac{G}{G_{ref}}.\Delta T \qquad 3.10$$

$$P(Tc) = (1+k_{pp}(Tc-25)) * P\ max \qquad 3.11$$

Table 3.4. Empirically determined coefficients to predict PV module temperature

Module Type	Mount	*a*	*b*	*ΔT* (°C)
Glass/cell/glass	Open rack	-3.47	-0.0594	3
Glass/cell/glass	Close roof mount	-2.98	-0.0471	1
Glass/cell/polymer sheet	Open rack	-3.56	-0.0750	3
Glass/cell/polymer sheet	Insulated back	-2.81	-0.0455	0
Polymer/thin-film/steel	Open rack	-3.58	-0.113	3

Source (Abdelhamid, 2014)

The cell temperature evolution of an insulated roof, as well as the reference temperature evolution of a normal white lorry roof under the illumination of Gref = 1000 W/m2, is experimentally analyzed in ambient temperatures in the range of 0 – 50℃.

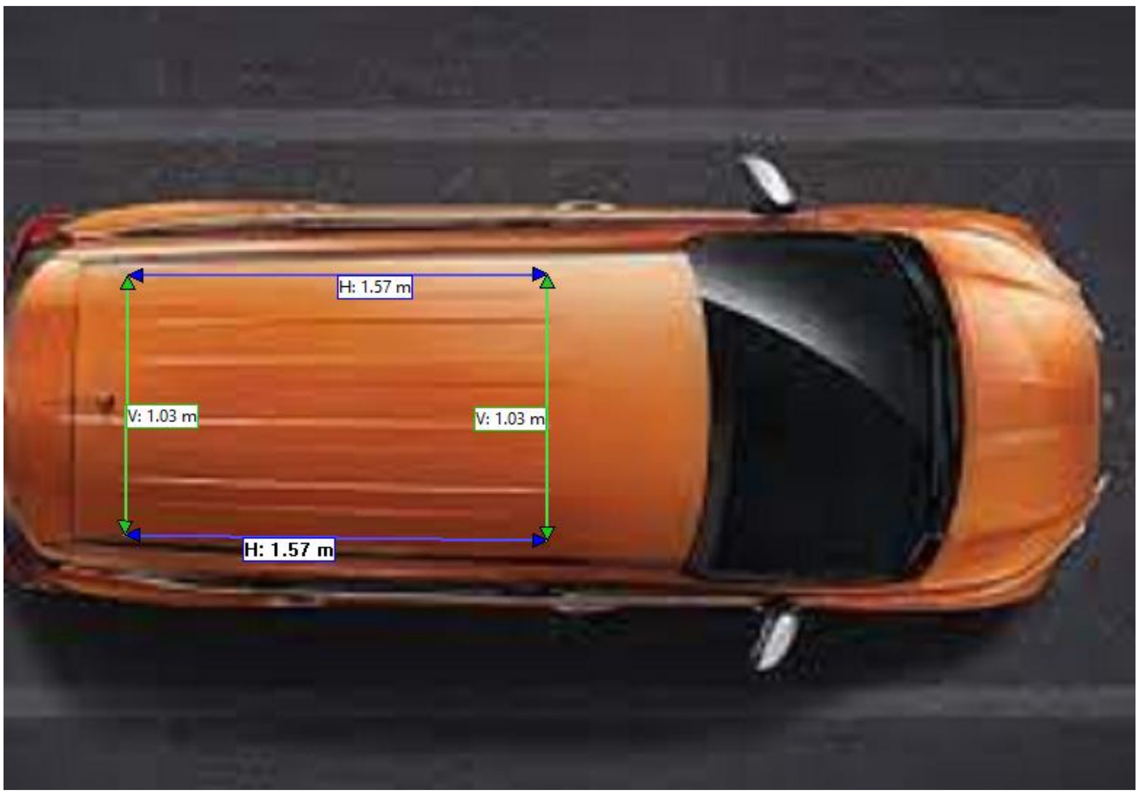
The five input parameters (ideality factor, diode reverse saturation current, photocurrent, series, and shunt resistance at STC) are mostly provided by the manufacturer's data sheet.

3.2.8 PV tilt Angle and orientation

Assuming the PV module is fixed and is oriented to the south (Azimuth=0^o) as shown in figure 3.4, the total incident irradiation is changed based on the value of the tilt angle. Let the tilt angle is varying between 0^o (horizontal configuration) to 90^o (vertical configuration) in maximum and minimum months.

3.2.9 Module Sizing and layout vehicle

Two PV system configurations are considered in this paper: one where modules are mounted only on the roof of the vehicle, and another where modules are mounted on the sides and back of the vehicle as well. The sizing of the modules on the roof of the vehicle is described below.



The size of the PV modules is estimated from the vehicle geometry and is used to estimate the rating of the roof and side PV systems(Arsie et al., 2005). The vehicle is approximated as a box that is 1.57 m horizontal, and 1.03 m vertical with clearance, with dimensions estimated from manufacturer specifications for sun power of PV. To maximize the impact of on-board photovoltaic, all possible surfaces should be exploited as mentioned in Chapter 2 Each of those areas is then multiplied by the surface power density, *SPD*, under standard reporting conditions (SRC), which are an operating temperature of T_{SRC} = 25 ◦C and radiation of G_{SRC} = 1000 W/m^2 (Walley, 1964). The SRC is the laboratory test conditions under which commercial and research PV modules are rated. This produces the rated power, *Prated*, of the module under SRC as described in Equation (Mallon et al., 2017). To avoid writing redundant equations, the bus surfaces are indexed by a subscript *i*, with *i* = *top*, *right*, *left*, *back* referring to each surface of the bus. Then:

$$Prated,i = Apv,i \times SPD \qquad 3.12$$

3.3. Life Cycle Assessment (Tank to Wheels) Vehicle Integrated of PV

3.3.1. Fuel Economy before PV Added Electric vehicle (EV) and ICE

Table 3.5 shows eight different Vehicles were selected,2021 models in this study for benchmarked, which 2021 NISSAN 370Z, Altima, Armada, Maxima, Leaf, Kicks, Sentra, and NV200 cargo are the first solar-powered family car developed by Solar team Eindhoven(*World's First Electricity Producing Solar-Powered Family Car*, 2020.).

The combined fuel economy (mpg) was calculated (before the PV is added) for all the above vehicles as shown in Figure 2.3 by assuming all the vehicles are with conventional internal consumption engine with η_{T2W} city =15 % and η_{T2W}Hwy = 20%.(Abdelhamid et al., 2016)

As shown in Table 3.5 below eight different electric vehicles 2021 models used in this paper for benchmarked,

Table 3.5. Nissan vehicle selected

Vehicle	Parameters				
Numbers	Cd	Cr	Af (m^2)	A side (m^2)	M v
NISSAN 370z roaster	0.3	0.008	2.4	7.84	1466kg
Nissan leaf	0.28	0.008	2.8	8.02	1715kg
Nissan Armada	0.31	0.008	3.9	10.77	2708kg
Nissan Murano	0.31	0.008	3.2	9.36	1734kg
Nissan Altima	0.26	0.008	2.6	9.07	1517kg
Nissan Maxima	0.29	0.008	2.6	9.10	1622kg
Nissan Kicks	0.3	0.008	2.8	7.6	1224kg

Nissan Sentra	0.29	0.008	2.6	8.4	1349kg

Source (https://www.guideautoweb.com/en/makes/nissan/maxima/2020/specifications/sl/)

All the above vehicles are analyzed in many aspects. Let take, vehicle on the above table shown the curb weight in kilogram (kg), aerodynamic coefficient, rolling resistance, frontal area, and side area for the above electric vehicles. The highest curb weight in the case of Nissan Armada is around 2708kg with the lowest one Nissan Kicks 11224 kg. On the other hand, Electric vehicles, a curb weight between 1224 kg to 2708 kg. The above vehicle was calculated by using the drag coefficient calculation tool *(Appendix 5)*.

3.3.2. Energy Storage and Vehicle Energy at Wheels

The energy demand at the wheels (*EW*) for a given driving cycle and given vehicle is calculated in equation 3.26. Nevertheless, to achieve the energy storage at wheel, the vehicle model aims to capture the primary forces on the vehicle while maintaining model simplicity. It is estimated that the driver accurately follows the reference velocity of the drive cycle. This assumption eliminates the need for a driver model and, because it is known, the vehicle model estimates inertial forces on the car and losses due to gravitational force, aerodynamic drag and rolling resistance, and other sources of power loss, such as gearbox friction, are neglected. The aerodynamic drag F_d is dependent on air density (ρ), frontal area (A_f), drag coefficient (Cd), and vehicle velocity (v), as described in Equation (3.13). The rolling resistance F_{roll} is dependent on total mass (m), gravitational acceleration (g), road incline *q*, and rolling resistance coefficient Cr, as described in Equation (3.14). The gravitational force gravity also depends on total mass, gravitational acceleration, and road incline, as described in Equation (3.15):

The energy at wheels were calculated for a given driving cycle and given vehicle listed below from equation 3.13-3.17

$$F_W = Fdrg + Fr + Fg + Fa \qquad 3.13$$

$$F_{drg} = \frac{1}{2}\,\rho * Cd * Af * Veff \qquad 3.14$$

$$F_r = Mv*g*\cos(\alpha)*Cr \qquad 3.15$$

$$Fg = Mv*g*\sin(\alpha) \qquad 3.16$$

$$Fa = (Mv+Mr)*\frac{dv}{dt} = 1.1\ Mv*\ v*\ \frac{dv}{dt} \qquad 3.17$$

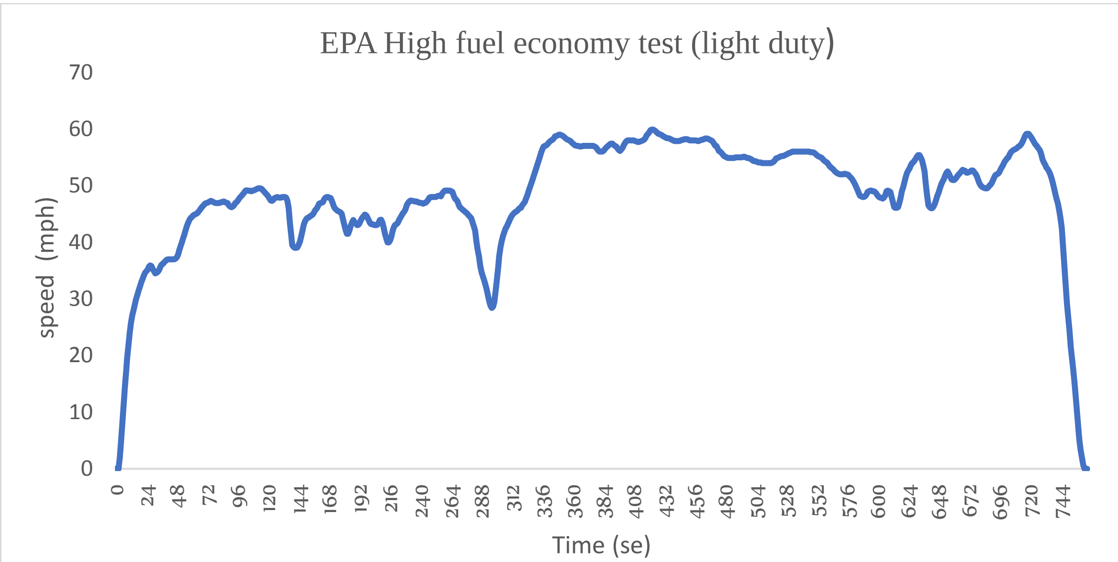
Were,

F_W= the forces at the wheel/ Traction
F_{drg} = aerodynamic drag force
Fr= rolling resistance force
Fg=gravitational force
Fa= acceleration force due to velocity / force of inertia
ρa =density of ambient air (1.225 kg/m^3)
Cd= Aerodynamic drag coefficient
Cr= Rolling resistance coefficient
Af= frontal area
Mv= mass of vehicle
Mr=rotational inertia
‘g= gravitational constant acceleration ($9.81m/s^2$)
a= slope of road equal 0 if no grade is assumed

Based upon the above calculation the power at the wheels (P_w) is calculated by the equation below.

$$Pw = Fw * V \qquad 3.18$$

$$EW = \int_{cycle} PW * dt \qquad 3.19$$



Source (EPA, 2020).

Figure 3-11.EPA high fuel economy test (Light duty)

3.3.3. Mile per gallon Calculation

The fuel economy in terms of a mile per gallon (MPG) in given driving is calculated using the equation 3.20 and 3.21. Without and with PV respectively.

$$MPG = \eta_{T2W} * \frac{Egasoline}{E\ cycle} * I\ cycle \qquad 3.20$$

$$MPG = \eta_{T2W} * \frac{Egasoline}{E\ cycle - Epv\ atwheel} * I\ cycle \qquad 3.21$$

Were,

$\eta_{T2W=}$ Tank to Wheels efficiency

$E_{gasoline}$ = Energy in one gallon of gasoline

E_{cycle} = Energy needs for the given cycle

$E_{pv\ at\ wheel}$=Energy for PV generation

I_{cycle}= Driving cycle length in miles

$E_{gasoline}$ is assumed 33.700 kWh/gal (Fitria, 2013), I_{cycle} depends on the driving cycle E_{cycle} vehicle parameters as well as driving cycle. The η_{T2W} is changed based on Powertrain configurations and driving cycle (Abdelhamid, 2014).

The PV energy that reaches the wheels in a given driving cycle is calculated using the proposed Equation.

$$E_{pv} \text{ at wheel} = T_{cycle} * \eta_{pv2W} * E_{PV\,hourly} \qquad 3.22$$

Were,

EPV –hourly is the hourly energy estimated for different locations and different driving patterns.

T cycle, is the cycle duration (in hour), (e.g., *Tcycle* =0.38 in city cycle and *Tcycle* = 0.2125 in highway cycle).

η_{PV2W} is tank-to-wheel efficiency from PV module to wheels, assumed here 90%.

The combined fuel economy (CFE) is calculated based on city and highway driving cycles (FE) using Equation (3.23). The weights of the city and highway driving cycles are considered as 55 percent and 45 percent, respectively.

$$FE_{combined} = \frac{1}{\frac{0.45}{FE\ city} + \frac{0.55}{FE\ highway}} \qquad 3.23$$

Miles per gallon gasoline-equivalent (MPGe) is used to calculate the vehicle's fuel economy for alternative fuels other than internal combustion engines (3.24).

$$MPGe = \frac{Total\ miles\ driven}{\frac{Total\ energy\ of\ all\ fuels\ consumed}{energy\ of\ one\ gallon\ of\ gasoline}} = \frac{33700}{EM} \qquad 3.24$$

Where, EM = Tank to wheel efficiency, electric energy consumed per mile (Wh/mile).

3.3.4 Electric Vehicles Powered by PV modules

In this section, I evaluate the overall driving ranges for EVs powered primarily by PV modules using the mono-Si PV option, which was ranked first in my study. I also divided the three scenarios into three categories: best, intermediate, and worst. The proposed EV is lightweight and aerodynamically efficient. In addition, assume that the EV owner has two sets of PV modules and batteries for all scenarios. The other set is assumed to cover an area of 5 m^2, which will be used to charge batteries at home. The assumptions of the vehicle, PV module, operating location, and the battery is in (Appendix 2). For the given vehicle, calculation the power demands (*PW*) at the wheel using the EPA driving cycle using.

$$Pw= \frac{1}{2}\rho C_d A_f V^3 + C_r M\, gV + M_{eff} V \frac{dv}{dt} \qquad 3.25$$

The energy to be provided at the wheel over the driving cycle is calculated by

$$E_w = \int_{cycle} PW\,dt = \frac{1}{2}\rho C_d A_f \int v^3 dt + C_r M g \int v\, dt + M_{eff} \int v \frac{dv}{dt} \qquad 3.26$$

The power demands at the wheel and the driving cycle. The driving range (*R*) is calculated on equation (3.27).

$$R= \frac{EW}{E\ bat} * D \qquad 3.27$$

Where, D is driving cycle distance and Ebatt is the amount of battery energy that reaches the wheel, which is given by

$$E_{batt} = \eta * \Delta SOC * E_{int} \qquad 3.28$$

Here, η is the traction efficiency and is equal to the product of that efficiency of each component: motor, batteries, etc. *SOC* is the operating window of the battery state of *Eint* is the initial energy stored in the battery from the PV, which differs in the three proposed scenarios

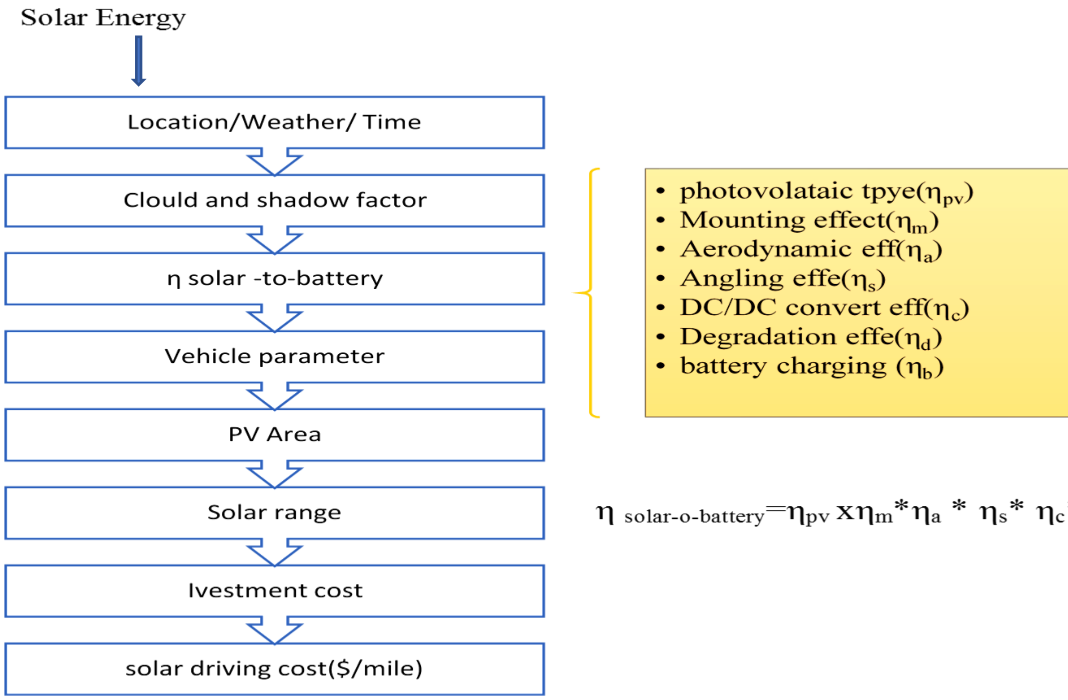
3.3.5 Carbon dioxide Reduction

Estimation the amount of carbon dioxide (Co_2) reduction per day for this assumed compared to an equivalent gasoline vehicle and the equivalent mile per gallon for the assumed vehicle in the driving cycle as 51 MPG.

The calculations are based on

$$MPG = \eta_{T2W} * \frac{\rho gasoline}{E\ Cycle} * I_{cycle} * 2.352 \qquad 3.29$$

3.4 Data Analysis



$$\eta_{\text{solar-o-battery}} = \eta_{pv} \, x \eta_m * \eta_a * \eta_s * \eta_c * \eta_d * \eta_b$$

Figure chart analysis of on -board PV for EV

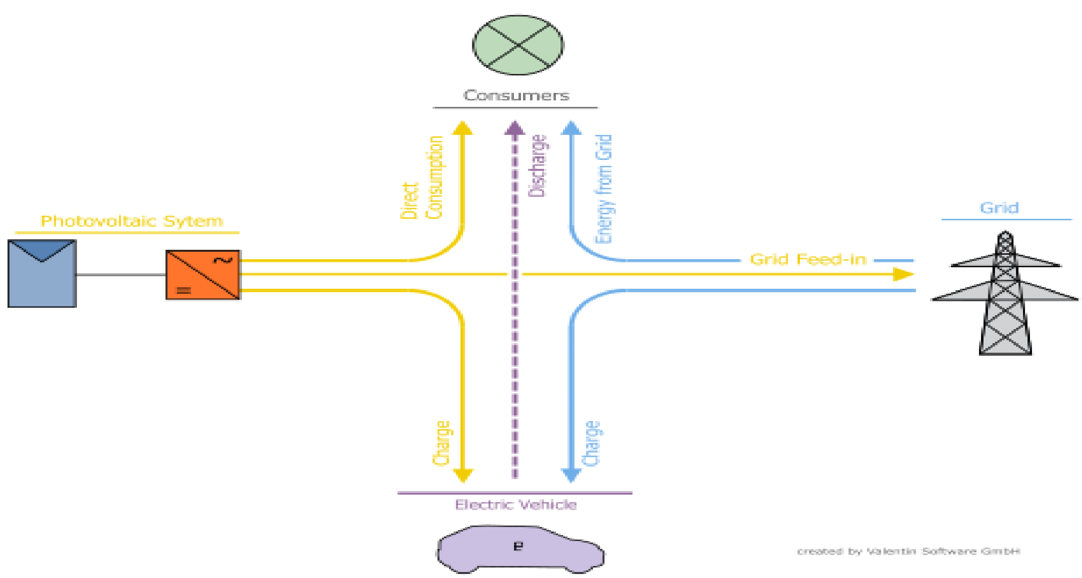


Figure 3. -10 flow diagram analysis off-board PV for EV

4. RESULTS AND DISCUSSIONS

4.1 Energy output of onboard VIPV

Many parameters are investigated with the purpose of PV energy output for vehicle application by optimizing the ratio of solar energy to the DC electricity output.

4.1.1 Mounting configuration effect on PV cell temperature

Figure 4.1 shows the effects of the different mounting configurations on the PV module the temperature in February in Ethiopia. In general, the open rack configuration is preferred to keep the PV module temperature as low as possible. The glass/cell/polymer sheet configuration has both the highest and lowest PV cell temperature depends on mounting option. The lowest (best) when the open rack is used and the highest (worst) in insulated back option. For other scenarios, the PV temperature will be less, so this shows an extreme case.

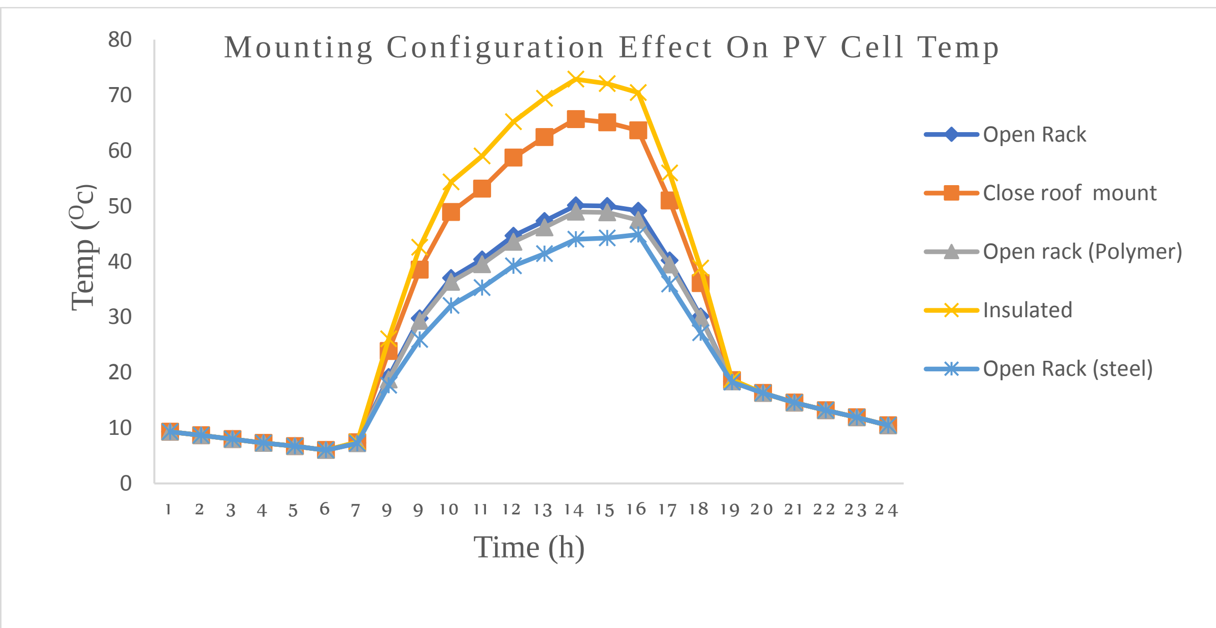


Figure 4-1.mounting configuration effect on PV cell temperature

Figure 4.1 showed the PV output power for different scenarios in February. The theoretical scenario is when the PV cell temperature is equal to ambient temperature. The worst option is when the temperature is increased (insulated back).

4.1.2 Effect of Shadow and Sky Clearness

As discussed previously in chapter 3 in Equations 3.4 & 3.5, the two components that comprised GHI are DHI and DNI. The direct component DNI reaches the PV module affected if there are any shadows on the PV module (e.g., the shadow created by nearby buildings, large vans, trees, etc.). The DHI component could be affected and minimized based on the sky clearness, which is the the factor that the sky is obstructed. The Equations (3.4) and (3.5) represent the GHI in both parking and driving modes.

If ϑ =1, there is no shadow while if ϑ =0 means there is complete shadow. If φ =1 means the sky is clear, while φ =0 means the clearness of the sky is completely blocked. Generally, ϑ & φ factors are changed with time and depend on many factors as weather, surroundings, locations, etc. In addition, ϑ & φ could affect the PV module partially and not the entire module and could have different values in different sections of the module. For that, the PV module designs have bypass diodes connected in parallel with each group of series PV cells to separate the shaded or bad cells and not affected the entire PV module. Depending on the case for a specific time, the PV power output could be predicted.

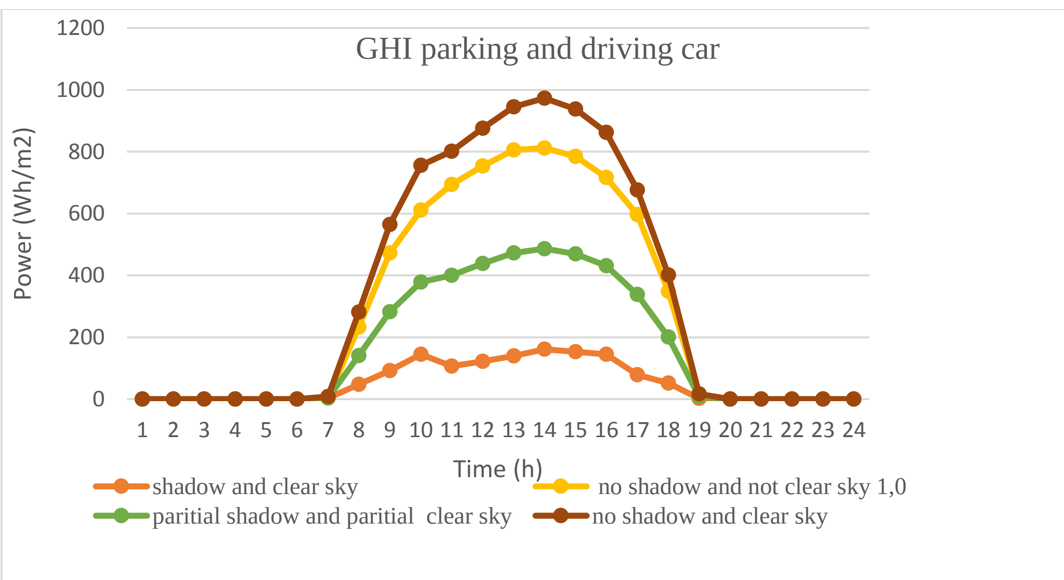


Figure 4-2. GHI in February parking and driving car

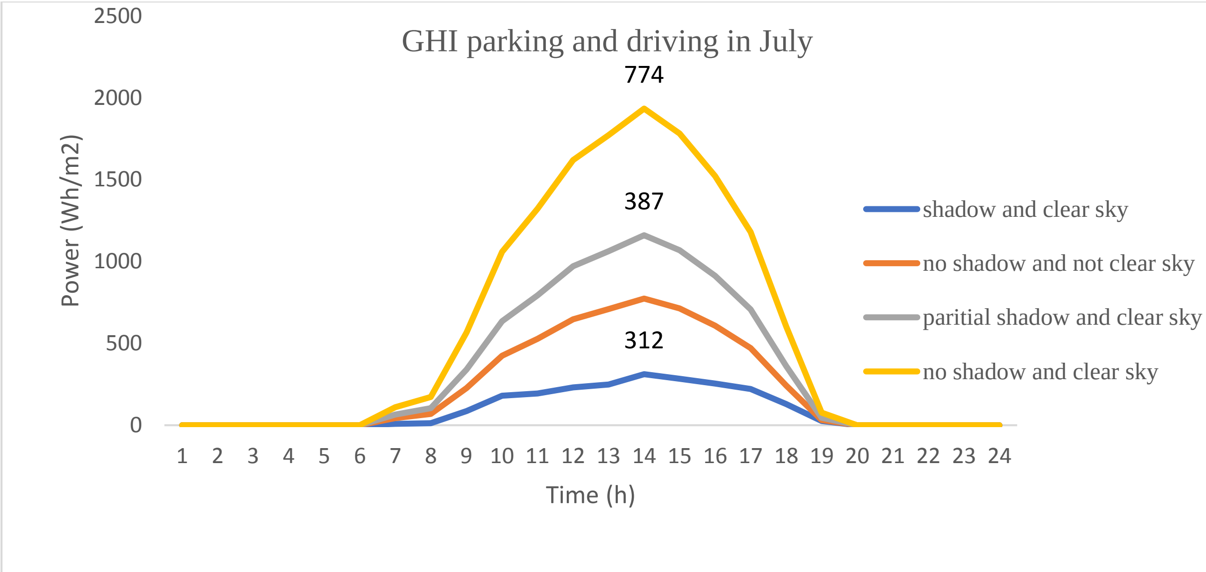


Figure 4-3. GHI in July parking and driving car

As discussed below total incident radiation on February and July for different shadow Scenario, when no shadow (ϑ=1), ϑ=75% are free from shadow and, only 25% are free from shadow the result is shown that in figure 4.4 and figure 4.5 showed that the total incident radiation in February and July, respectively, for the same ϑ & φ assumptions. In this case, ϑ & φ =1, the PV module is in the sun for all periods, and the sky is clear. If ϑ=1 & φ=0, the PV module is in the sun, but the sky is not clear at all. If ϑ=0 & φ=1, the sky is totally clear, but the PV module is under a complete shadow all the time. Based on the above calculations, even if the PV module is located in the shadows all the time, the GHI still reaches 25% of the maximum GHI if the sky is clear. If there are partial shadow and partial sky clearness (e.g., ϑ=0.5 & φ=0.5) the GHI is reduced to 75% compared to the ideal case. When total shadow and clear sky the power generator in July greater than February in figure 4.5.

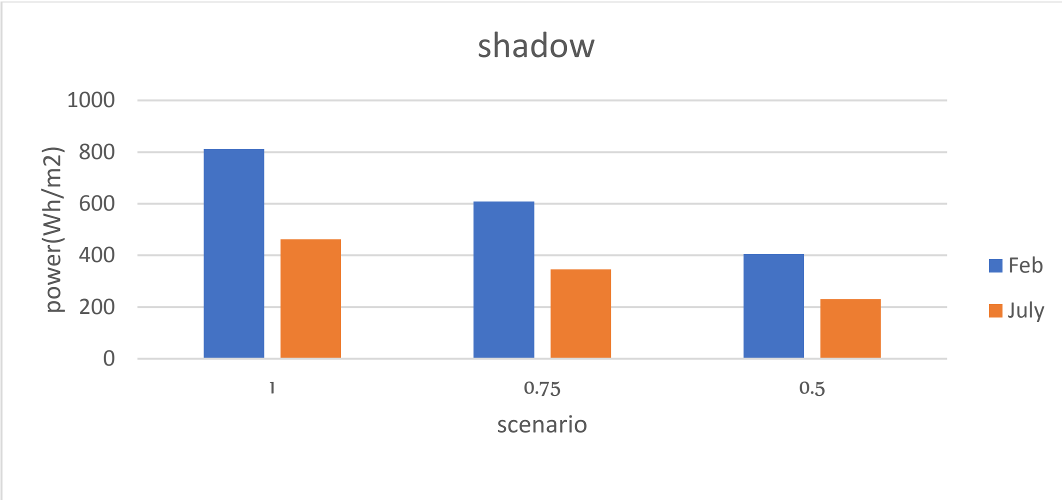


Figure 4-4. Total incident radiation on Feb & July in different shadow scenarios

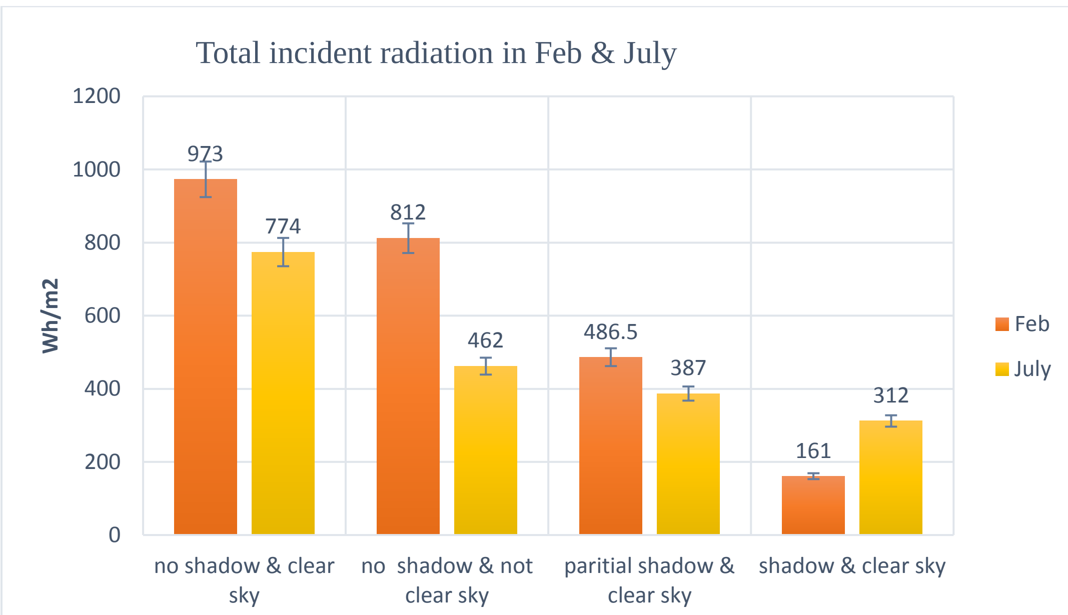


Figure 4-5. Total incident radiation on Feb & July in different shadow and sky clearness scenarios

4.1.3 PV Tilt Angle and Orientation

Assuming the PV module is fixed and is oriented to the south (Azimuth=180°) as shown in Figure 4.6, the total incident irradiation is changed based on the value of the tilt angle. Assuming the tilt angle is varying between 0° (horizontal configuration) to 90°.

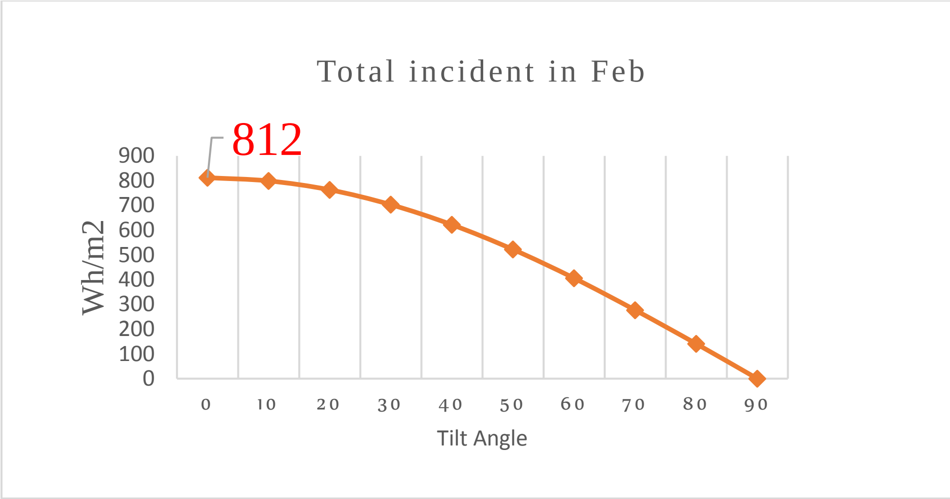


Figure 4-6. Total incident radiation Vs. Tilt angle in February

4.1.4 Modeling PV System Results

As shown in chapter three on table 3.3 based on the specification PV I selected and calculated the total daily energy Wh stored in the battery for varying PV modules are in February and July, respectively. The PV module area used with area 1.63 m^2 with the widths 1046 mm and the length is equal to 1559 mm detail expressed in Figure 3.9 typically; the vehicle surface can be fitted with this PV module with width.

The stored energy also depends on the location and, PV module efficiency as shown in Figure 4.7 assumed the PV module area is equal to 3.261 $m^{2,}$ and the PV module efficiency is equal to 20.4% which is the maximum theoretical of this module is greater than 20. 4 %. Figure 4.7 shows results in Ethiopia in February and July respectively.

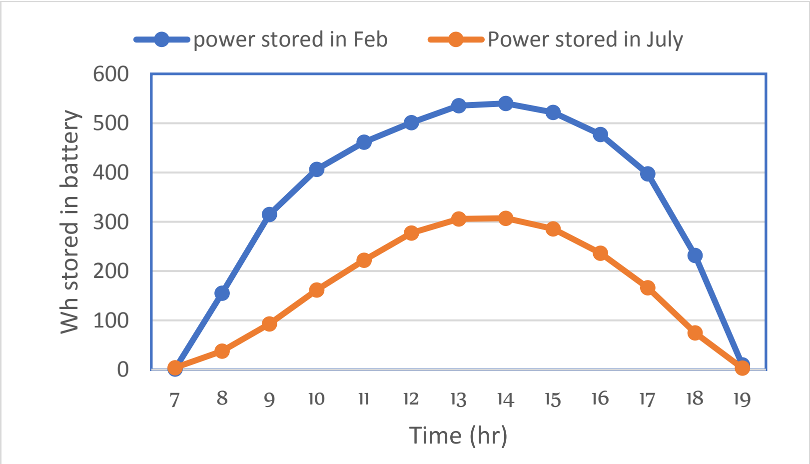


Figure 4-0-7. Hourly Energy Stored (Wh) in battery in Feb and July

Figure 4.8 shows the proposed model output in terms of the total daily energy (Wh) stored in a battery in different locations and months. In addition, the PV module efficiencies are varying to reflect future scenarios. In the PV module, the area is equal to 3.261 m^2. Total daily energy in Feb and July is equal to 6847 and 3271 Wh/m^2 respectively (Appendix 8).

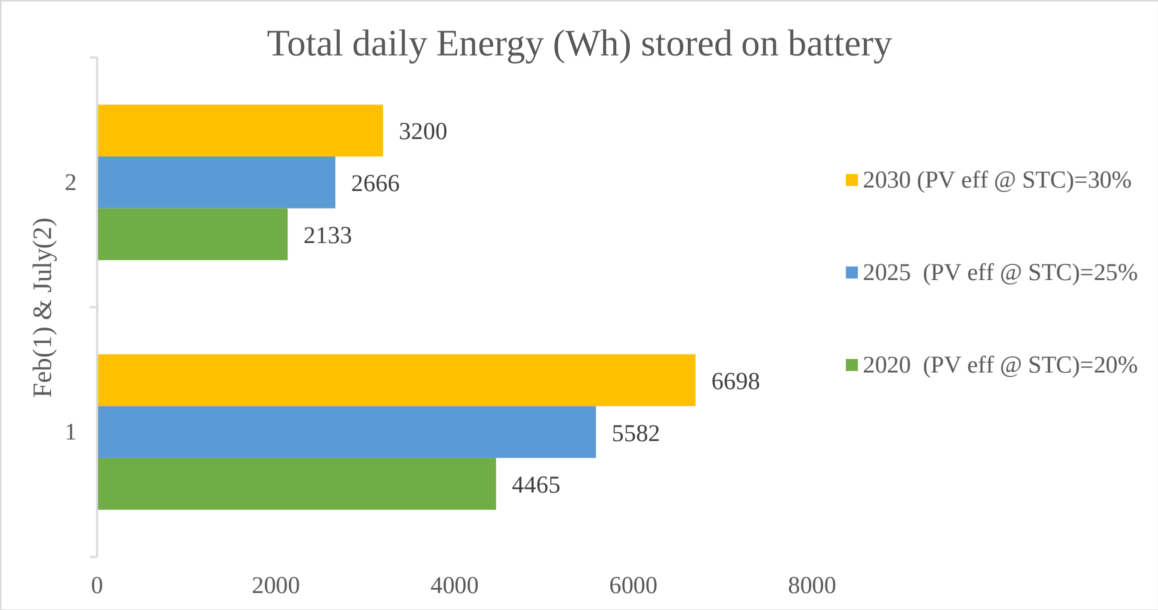


Figure 4-8. Daily Energy (Wh) is stored in the battery for different scenarios

Figure 4.9 shows the proposed model output in terms of the hourly energy (Wh) stored in a battery in different locations and months. The assumption here the PV module the area is equal to 3.261 m^2 and PV module efficiency at STC is equal to 20%.

Hourly energy stored on battery Photovoltaic area 3.261 m^2 at STC with the efficiency of 20%.

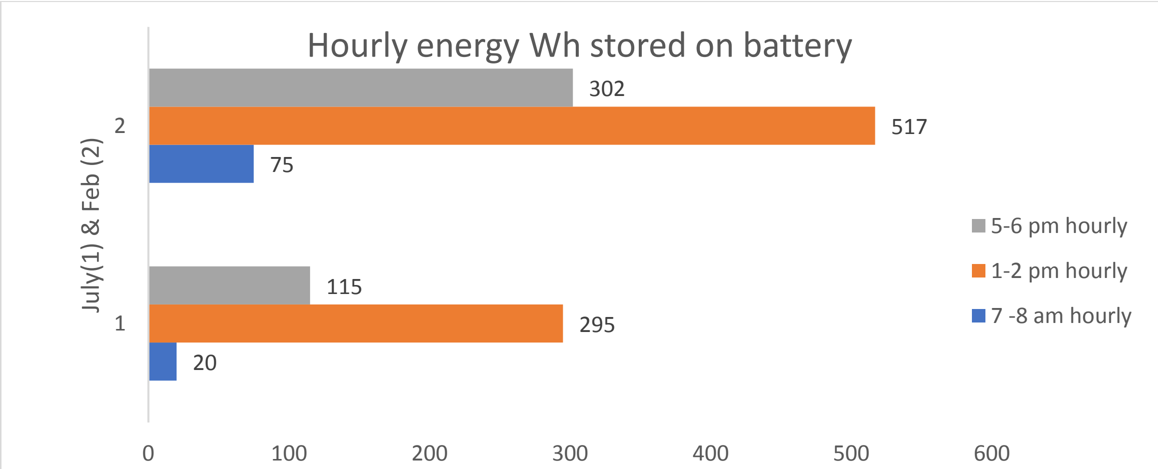


Figure 4-9. Hourly energy (Wh) stored in the battery for different scenario

Mostly, in each month in Ethiopia. In addition, in any month the results will be between July and February. In the next stage, the best-case scenario depends on February and the worst-case scenario depends on July is analyzed.

4.1.5 Contribution of On-board PV in increasing the Fuel Economy

The advanced estimation for a tank to wheel efficiency of this application requires further optimization stage to run for specific vehicle component size and specific driving pattern. The idea here is to decrease energy conversions losses by using any available solar energy directly to the wheels without storing the energy in the battery unless if the system is forced to do that (e.g., SOC). The analysis was done on eight different vehicle specifications to cover a wide range of vehicles. The vehicle parameters are shown in Table 4.1

Table 4-1. Nissan vehicle selected with the specification.

	Type of vehicle	Cd	Cr	Af	As	Mv	MPG	Wh/mile
1	2021 NISSAN370Z	0.3	0.008	2.4	7.8	1466	69	328
2	2021 Nissan Altima	0.26	0.008	2.6	9.0	1517	68	364
3	2021 Nissan Maxima	0.29	0.008	2.6	9.1	1622	63	343
4	2021 Nissan Armada 4WD	0.31	0.008	3.9	11	2708	38	205
5	2021 Nissan Leaf	0.28	0.008	2.8	8	1715	60	368
6	2021 Nissan Kick	0.34	0.008	2.8	7.5	1224	76	332
7	2021 Nissan Sentra	0.26	0.008	2.6	8.4	1349	75	338
8	2021 Nissan NV200 Cardo VA	0.31	0.008	3.2	8.1	1487	65	349

To calculate power loss, gain and net are based on PV system configuration mounted on roof Nissan sentra vehicle taken as an example.

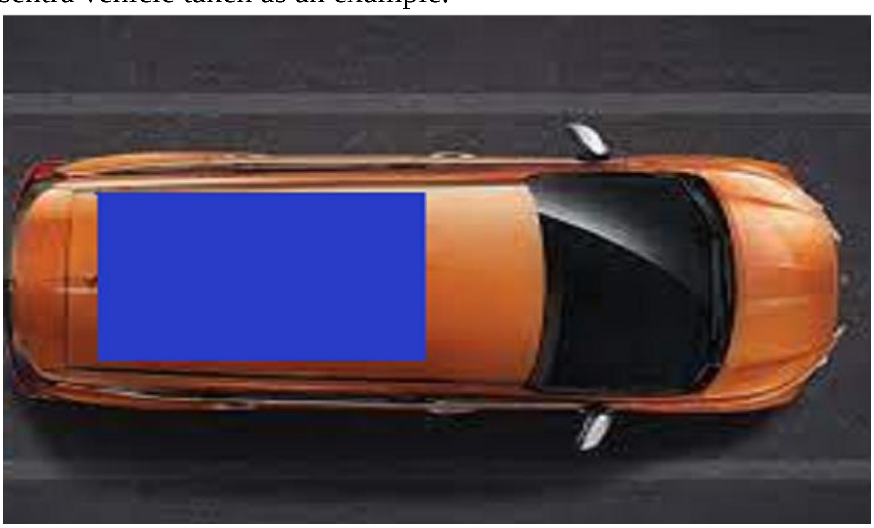


Figure 4.10. PV systems mounted on roof of vehicle

The power loss due to the added mass of PV module, mounting, battery, electric motor, and increase in the frontal area of vehicle ranges from 140.8 W to 156.28 W, and the power generator from PV ranges from 492.6 W to 759.3 W. The net power ranges from 336.36 W to 613.63 W, which is the difference between power gain and power loss. (See detail calculation on Appendix - 9)

Table 4-2. Power analysis by PV added on-board to gasoline vehicle

Type of vehicle	power loss(w)	Power gain(W)	Power net(W)
2021 NISSAN370Z	156.28	492.6	336.36
2021 Nissan Altima	140.8	520.4	379.62
2021 Nissan Maxima	143.05	518.6	375.51
2021 Nissan Armada 4WD	145.69	759.3	613.63
2021 Nissan Leaf	143.57	557.5	413.88
2021 Nissan Kick	152.47	557.5	404.99
2021 Nissan Sentra	140.8	520.4	379.62
2021 Nissan NV200 Cardo VA	145.69	629.7	483.99

Figures 4.10, 4.11, and 4.12 show the before adding PV and increase in the combined MPG after adding the proposed PV on board for different conventional gasoline vehicles at 7-8 am, 1-2 pm, and 5-6 pm hourly, respectively. The increment in combined MPG is between a minor increase of 0.25 mpg to a major increment by 11mpg depends on vehicle specifications, time, location, and month. The y-axis in Figures 4.10 to 4.12 show the minimum and maximum increase in mpg for three driving times at 7-8 am 1-2 pm, and 5-6 pm. The minimum values refer to the vehicle is driven in July.

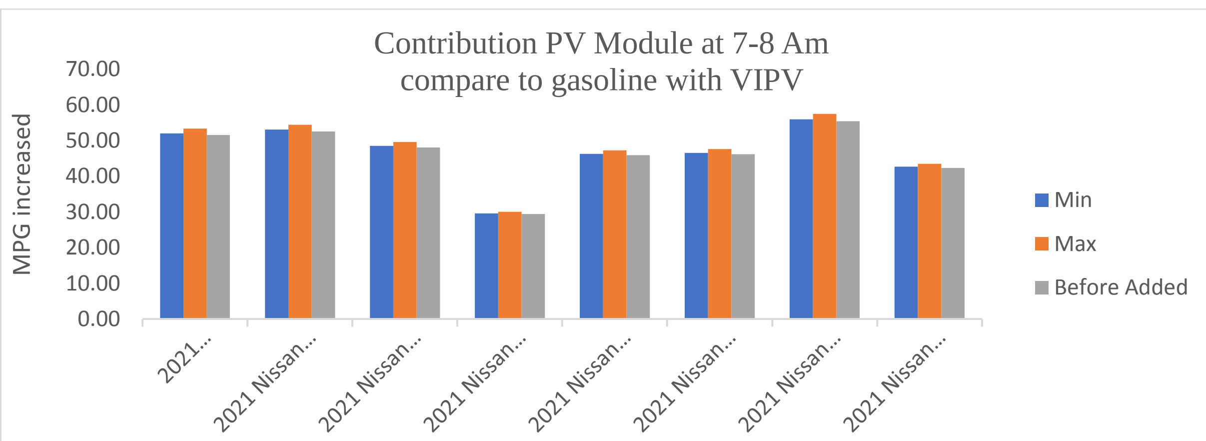


Figure 4-10. Onboard PV contribution in fuel economy (MPG) at 7-8 am a scenario

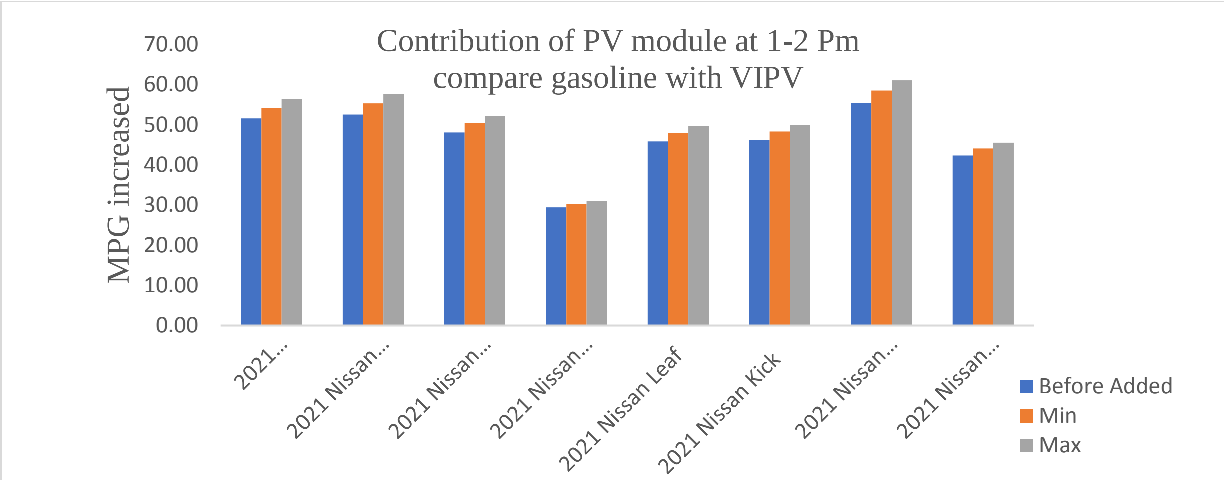


Figure 4-11.Onboard PV contribution in fuel economy (MPG) at 1-2 pm scenarios

The maximum values refer to the vehicle driven in February in Ethiopia. For specific vehicle parameters and specific drive time, the increment in the fuel economy is mostly between the minimum and maximum values represented in any month in a year. (Appendix- 7D)

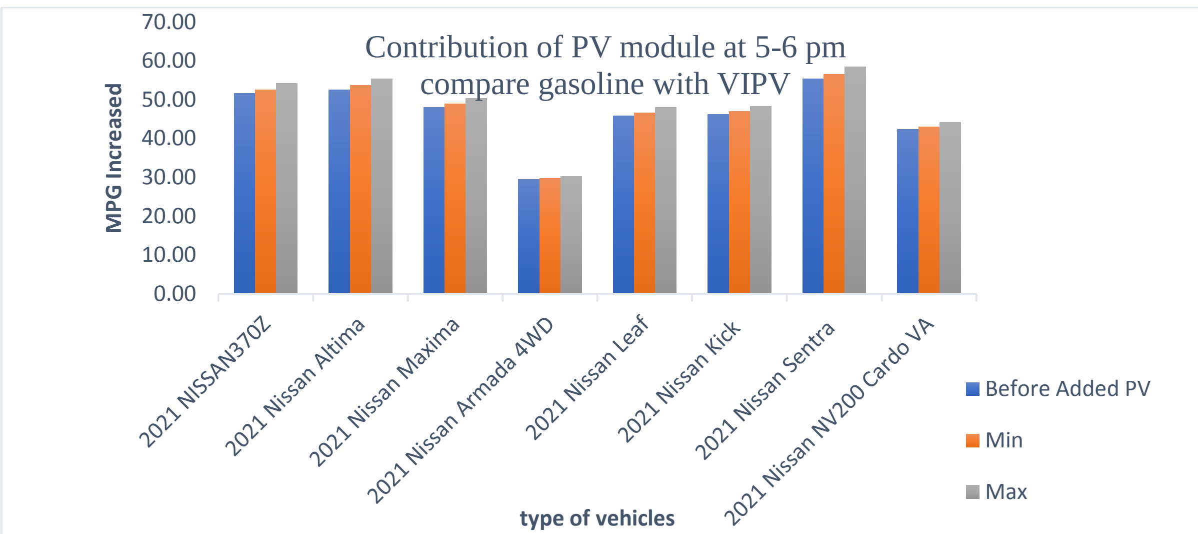


Figure 4-12. Onboard PV contribution in fuel economy (MPG) at 5-6 pm scenario

4.1.6. PV solar daily driving Range

Daily pure PV solar driving ranges are estimated in this section by adding the proposed PV module to eight vehicles (see figure 4.13.)Table 4.1 displays the vehicle parameters. Assume that all vehicles are electric and that the vehicle efficiency (Wh/mile) is shown in table 4.1. The extended daily driving range is shown in Figure 4.13 to be between 4 and 22 miles. The combined (Wh/mile) for the vehicle is calculated based on 55% and 45% driving cycles as a standard combined EPA cycle. (Appendix-9).

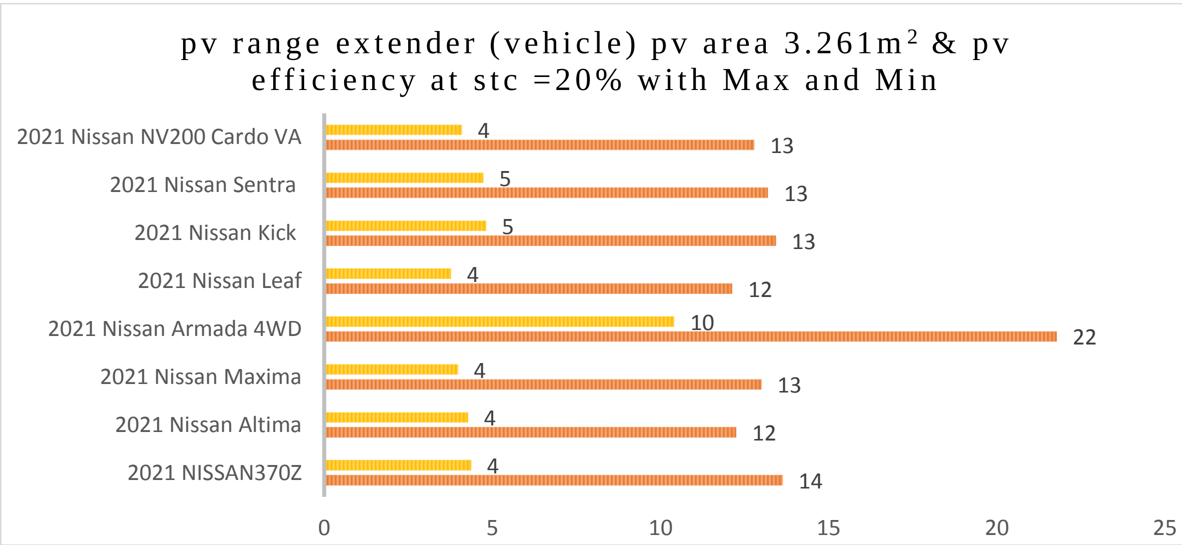


Figure 4-13.Onboard PV contribution in fuel economy (MPG) at 5-6 pm scenario

4.1.7. Cost analysis of on-board vehicle integrated PV

4.1.7.1Return on investment (ROI) of adding on-board PV system with plug-in EV

Under plug-in Electric vehicle detail the estimated rates of return on money (cost of adding on-board PV system) per period for a plug-in EV, otherwise known as ROI, as expressed in Equation (4.1).

$$\text{ROI (\%)} = \frac{Gain\ of\ Investment - cost\ of\ investment*}{Cost\ of\ investment} 100\% \qquad 4.1$$

The cost of investment in two scenarios (in Maximum and Minimum month energy generation estimation) is calculated using Equation (4.2) and the results were tabulated in (Appendix 2). The current cost estimation of the PV modules is estimated as a total of $616.0 based on current commercial prices for silicon PV module is $0.95/W with no tax(Abdelhamid et al., 2013); the proposed module is 654 W with 7.0% tax. However, PV cost in the low onboard solar photovoltaic system for plug-in electric vehicles. The cost of MPPT is estimated at $279.0 based on 0.4 €/W ($0.44/W)(Abdelhamid et al., 2013). The mounting cost with wires and fuses is estimated at $80.0 same as the roof-mounted cargo rack.

$$\text{Cost of Investment (\$)} = \sum [\text{PV Module} + \text{MPPT} + \text{Mounting} + \text{Installation} + \text{Maintenance}] \text{ for Plug-in EV} \quad 4.2$$

The installation cost is assumed 10% of the total system cost(Date, 2014), which is equal to $98.0 current and $68.0, the future price. The total maintenance cost is estimated at $148.6 or $114.7 The lifetime of the PV system (NL) is considered the same as the life of the vehicle was set at 12 years based on the average daily use of 22 miles, culminating in a total of 150,000 miles over the car's lifetime(Green et al., 2013). The total investment cost used in the following analysis is the mean value between the two scenarios. Electricity prices are used: ¢13/kWh (The average US in Nov 2015), (Saaty, 2012). The PV daily solar ranges are based on the minimum (i.e., driving in July and maximum scenarios (driving in February in Ethiopia) (see figure 4.14).

$$\text{Gain on Investment} = \left(\frac{1}{\frac{\text{Wh}}{\text{mile}}}\right) * \text{PV daily solar range} * \text{cost of electricity} \left(\frac{\$}{\text{kWh}}\right) * 365 * \text{vehicle lifetime in a year)} \quad \text{for Plug-in EV} \quad 4.3$$

The Vehicle was driven in the low solar climate of Ethiopia in July the Minimum ROI of adding on-board PV for different vehicles Plug-in electric vehicle had negative value to positive value in the range of - $48.98 to $135.65 and the high solar climate of Ethiopia in February the maximum of adding onboard PV for different vehicle plug-in the electric vehicle had positive value in the range of $56.46 to $398.26. (Appendix -7A)

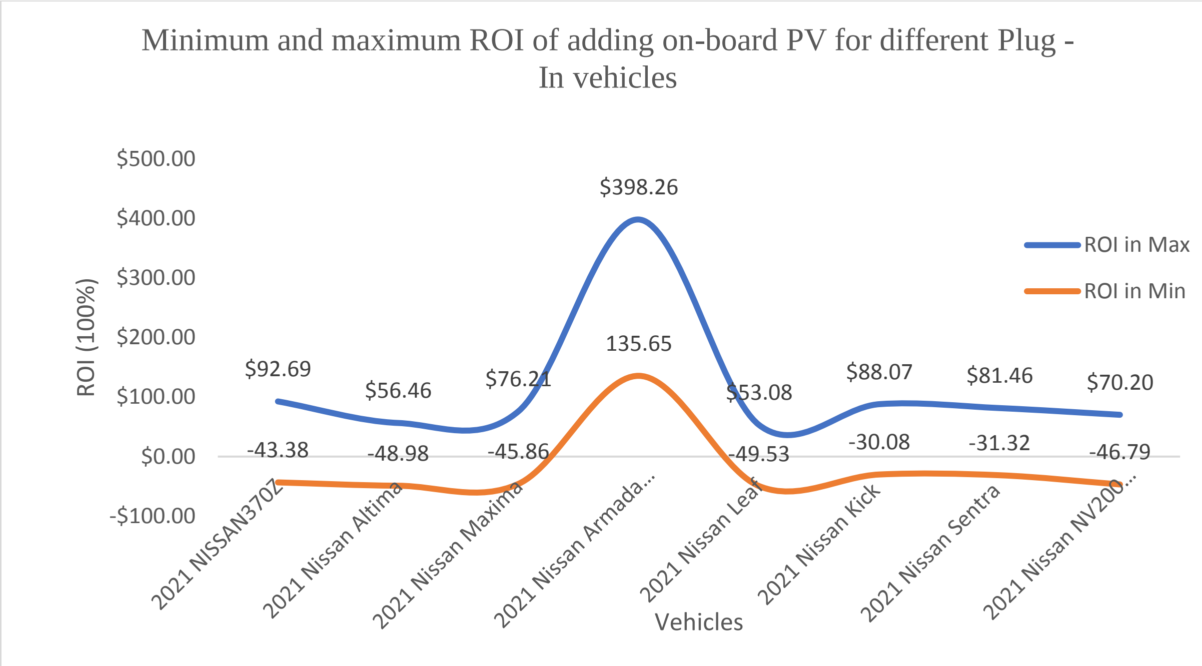


Figure 4-0-14.Minimum and Maximum ROI of adding onboard PV for different Plug-in vehicles.

4.1.7.2. Return on investment (ROI) of adding on-board PV system with ICE

This section details the estimated rates of return on money (cost of adding on-board PV system) per period for an ICE, otherwise known as ROI, as expressed based on equation (4.1).

The cost of investment in two scenarios (in Maximum and Minimum month energy generation estimation) is calculated using Equation (4.4) and the results were tabulated in (Appendix 2). The current cost estimation of the PV modules is equal to plug-in electric vehicles mentioned under plug-in EV. The mounting cost with wires and fuses is estimated at $80.0 same as the roof-mounted cargo rack.

$$\text{Cost of Investment (\$)} = \sum[\text{PV Module + Converter+ Mounting + Battery + Motor + Installation + Maintenance] for ICE} \quad 4.4$$

The costs of both the battery and motor with the controller were calculated using Equations (4.5) and (4.6), both of which are already in use in the NREL Future Automotive Systems Technology Simulator(Singh et al., 2014).

$$\text{Motor and Controller (\$)} = \$21.7/KW + \$425 \quad 4.5$$

$$\text{Battery (\$)} = \$22/KW + \$500/KWh + \$680 \quad 4.6$$

The installation cost is assumed 10% of the total system cost (Singh et al., 2014). A 2% maintenance cost per year (M/year) is assumed(Singh et al., 2014) of the total system cost with an expected inflation rate = 2.5% and an interest rate of 8%, based upon U.S NREL data (Singh et al., 2013). The vehicle life was set at 12 years based on the average daily use of 22 miles, culminating in a total of 150,000 miles over the car's lifetime.

$$\text{Gain on Investment} = \left(\frac{1}{\text{MPG}}\right) * \text{PV daily solar range} *$$

$$\text{cost of Gallon (\$/mile} *$$

$$365 * \text{vehicle lifetime in the year)} \qquad \text{for ICE} \qquad 4.7$$

The vehicle was driven in the low solar climate of Ethiopia in July, ROI had a negative value to positive value in the range - $50.86 to $ 66.61. However, when the car was driven in the high solar climate of Ethiopia with the price for a gallon of gas ROI was positive value in the range of $42.76 to $252.27. (Appendix-7B)

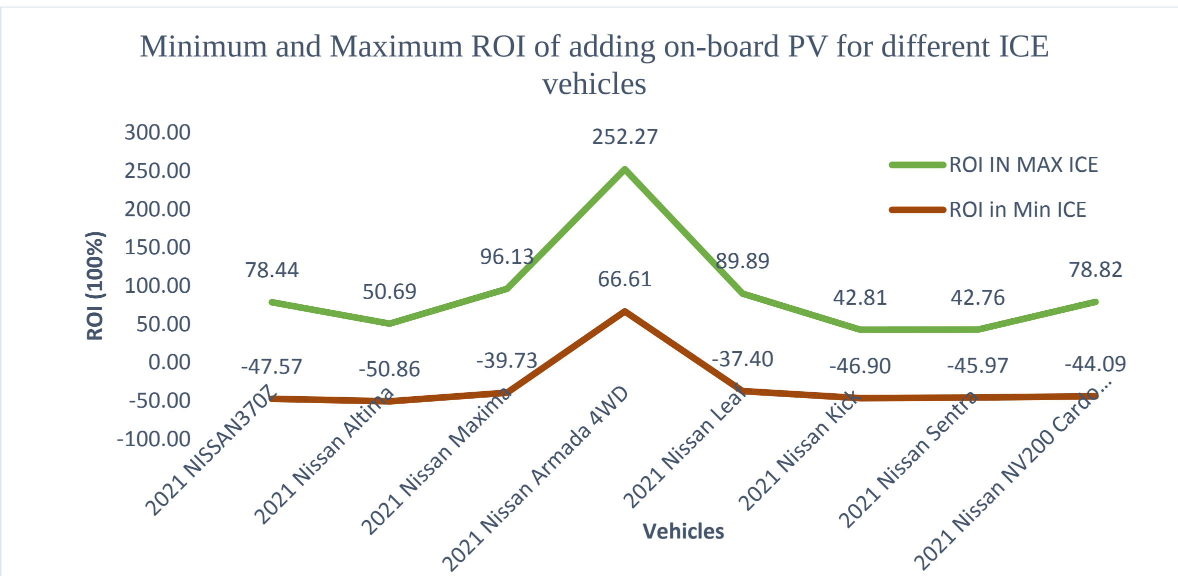


Figure 4-15. Minimum and Maximum ROI of adding on-board PV for different ICE

4.1.7.3 Return on investment (ROI) of adding on-board PV system with EV

Under Electric vehicle detail the estimated rates of return on money (cost of adding on-board PV system) per period for an EV, otherwise known as ROI, as expressed in Equation (4.1).

The cost of investment in two scenarios (in Maximum and Minimum month energy generation estimation) is calculated using Equation (4.8) and the results are tabulated in (Appendix 2). The current cost estimation of the PV modules is estimated as a total of $616.0 based on current commercial prices for silicon PV module is \$0.95/W with no tax (Abdelhamid et al., 2013); the proposed module is 654 W with 7.0% tax. The cost of the converter is estimated as \$190.0 and \$150.0 current and future prices respectively. The mounting cost with wires and fuses is estimated at \$85.0 same as the roof-mounted cargo rack.

$$\text{Cost of Investment (\$)} = \sum \text{[PV Module+ Converter+ Mounting + Installation + Maintenance] for EV} \quad 4.8$$

The installation cost is assumed 10% of the total system cost (Date, 2014), which is equal to \$89.0 current and \$54.99.0, the future price. The total maintenance cost is estimated at \$157.70 or \$95.5 based on each specific scenario(Date, 2014). The maintenance cost per year (M/year) is assumed 2% of the total system cost with assuming an inflation rate = 3% and an interest rate of 10% (Date, 2014). The lifetime of the PV system (NL) is considered the same as the life of the vehicle was set at 12 years based on the average daily use of 22 miles, culminating in a total of 150,000 miles over the car's lifetime(WRC, 2012). The total investment cost used in the following analysis is the mean value between the two scenarios. Electricity prices are used: ¢13/kWh (The average US in Nov 2015), (Saaty, 2012). The PV daily solar ranges are based on the minimum (i.e., driving in December and maximum scenarios (driving in Feb in Ethiopia) (see figure 4.16).

$$\text{Gain on Investment} = \left(\frac{1}{\frac{\text{Wh}}{\text{mile}}}\right) * \text{PV daily solar range} * \text{cost of electricity} \left(\frac{\$}{\text{kWh}}\right) * 365 * \text{vehicle lifetime in the year)} \quad \text{For EV} \quad 4.9$$

As shown in Figure 4.16 the car was driven in the low solar climate of Ethiopia in July, ROI had a negative value to positive in the range - \$45.45 to \$154.72 and in the high solar climate of Ethiopia in February, the car was driven with ROI, had positive value in the range of \$65.46 to \$438.58. (Appendix -7C)

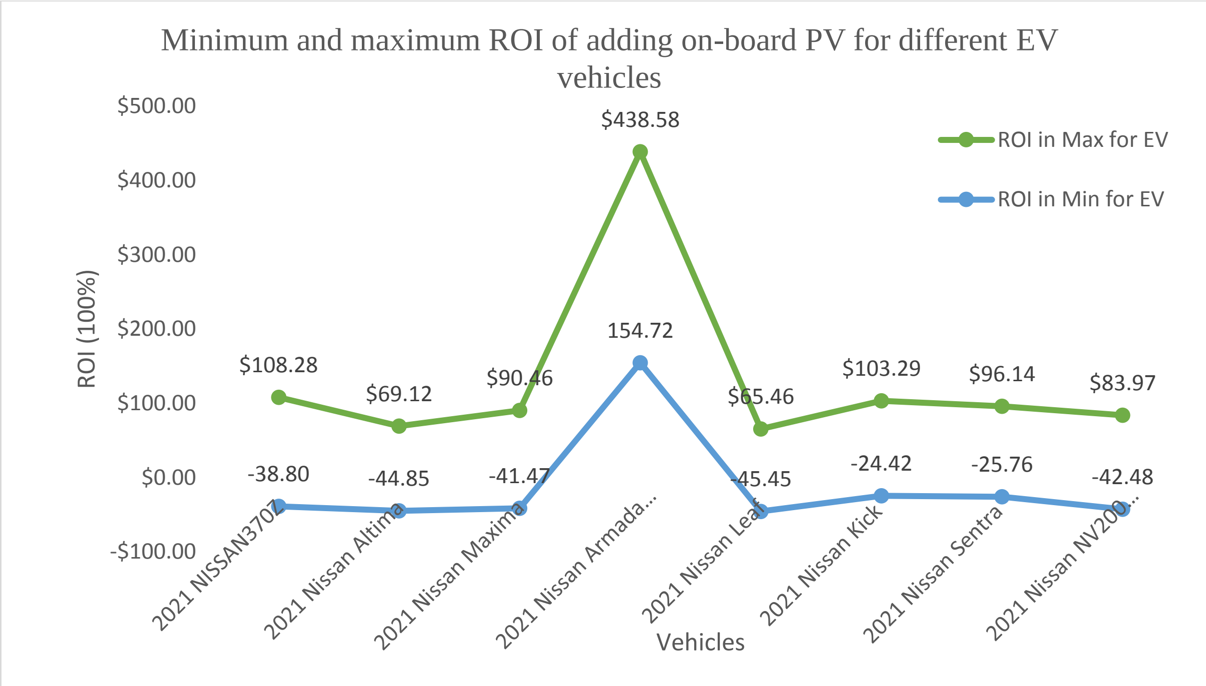


Figure 4-16. Minimum and Maximum ROI of adding on-board PV for different EV

4.1.8 Cost analysis and Environmental impact using GREET

4.1.8.1 Simple payback

In general, when compared mathematically, and simulation by using software GREET cost analysis Electric vehicles have more advantages than Hybrid Electric vehicles and plug-in Electric vehicles. When you see the results simulated in figure (4.17) the simple payback of Hybrid Electric vehicles is four (4) years, plug-in Electric vehicle is three (3) years and Electric vehicles two to half of the year (2.5) years.

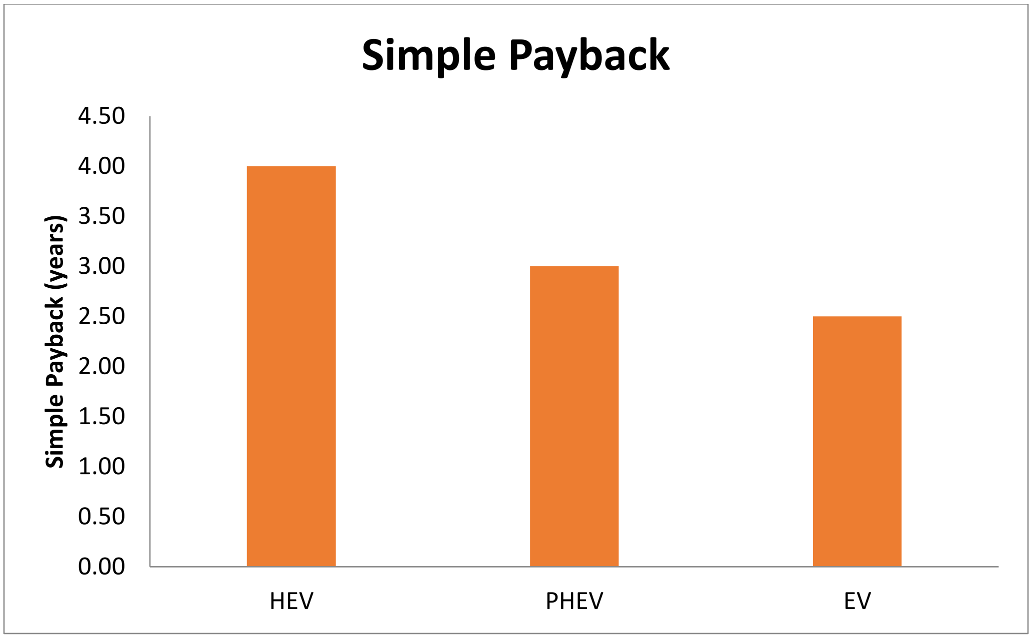


Figure 4-17. Simple payback of different vehicles system.

As indicated in figure 4.18 the annual greenhouse gas (GHG) emission of gasoline vehicles is 6 tons/year, if integrated with hybrid Electric vehicles, plug-in electric vehicles, and Electric vehicles the annual greenhouse gas emission is gradually decreased respectively.

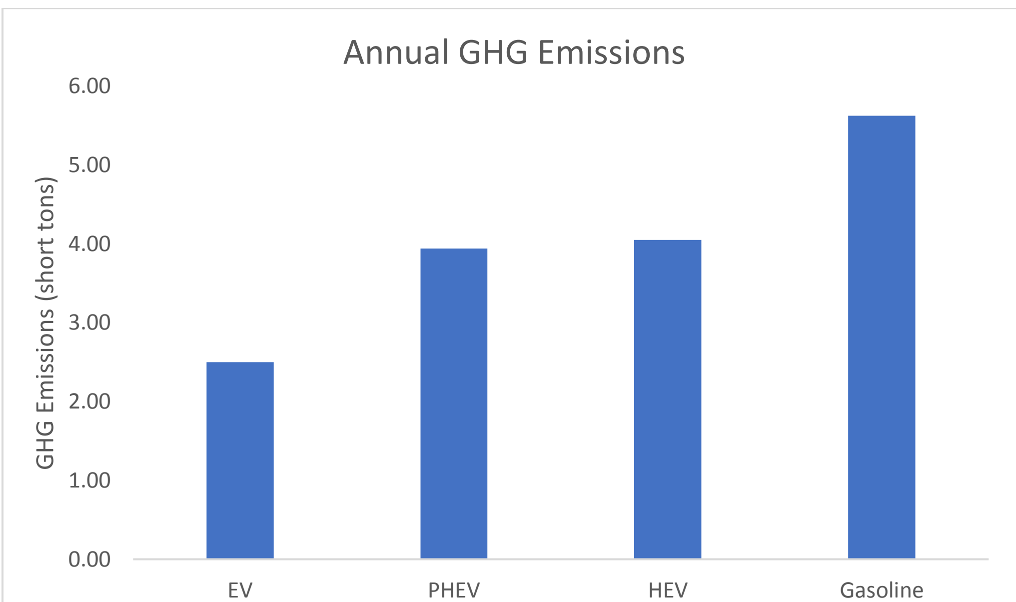


Figure 4-0-18. Annual GHG emissions of different vehicles system.

4.1.8.2 Annual petroleum use

As expressed in figure 4.19, I calculated the Annual petroleum use by using GREET software the gasoline vehicle uses petroleum 10 barrels/year. But, if to integrate with PV in different systems the annual petroleum use is decreased.

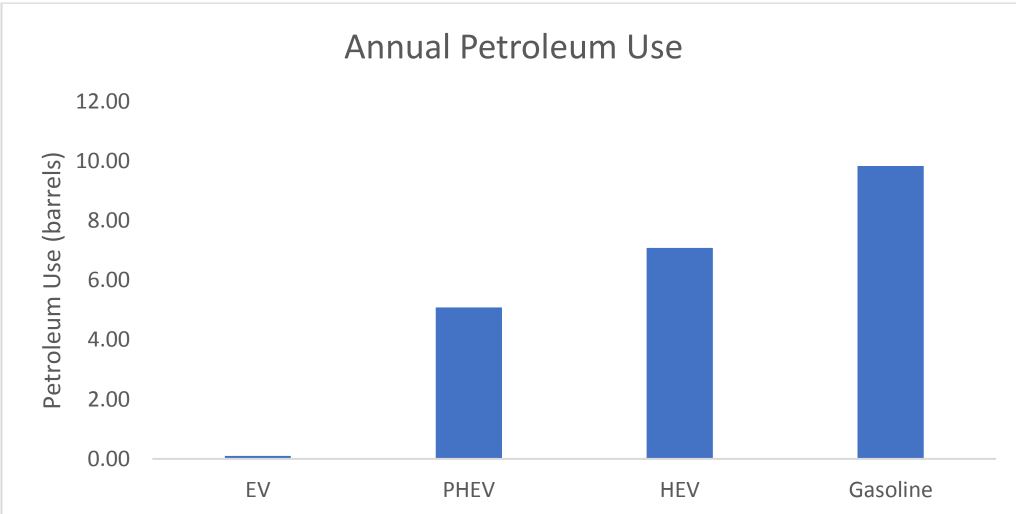


Figure 4-0-19. Annual petroleum use

4.1.8.3 Annual air pollutants

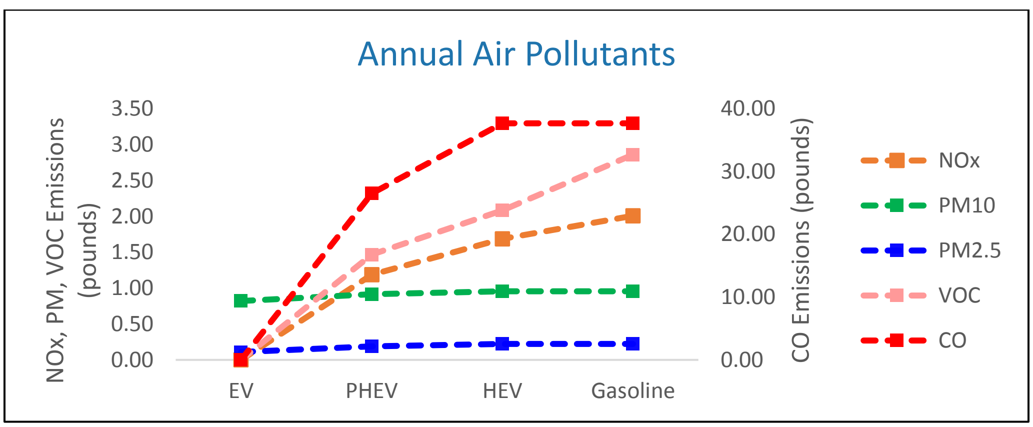


Figure 4-20.Annual Air pollutants to emit

Table 4-3. Amount of annual air pollutants each system

Fuel	CO	NOx	PM10	PM2.5	VOC
EV	0.00	0.00	0.82	0.11	0.00
PHEV	26.53	1.19	0.92	0.19	1.47
HEV	37.67	1.69	0.96	0.22	2.08
Gasoline	37.67	2.01	0.96	0.22	2.86

4.1.9. Evaluation Scenario Electric Vehicles Powered by PV modules

4.1.9.1 Best Case Scenario

The assumptions of the different scenarios are tabulated in (Appendix2). Here, it is assumed that either with or without efficient cooling, the average temperature on both PV modules is kept at an STC of 25°C. The power generated by the PV modules at home is equal to 1000 W. In the assumed location, the energy generated by the PV is approximately equal to 5000 Wh per day. (see detailed information in figure 3.11)

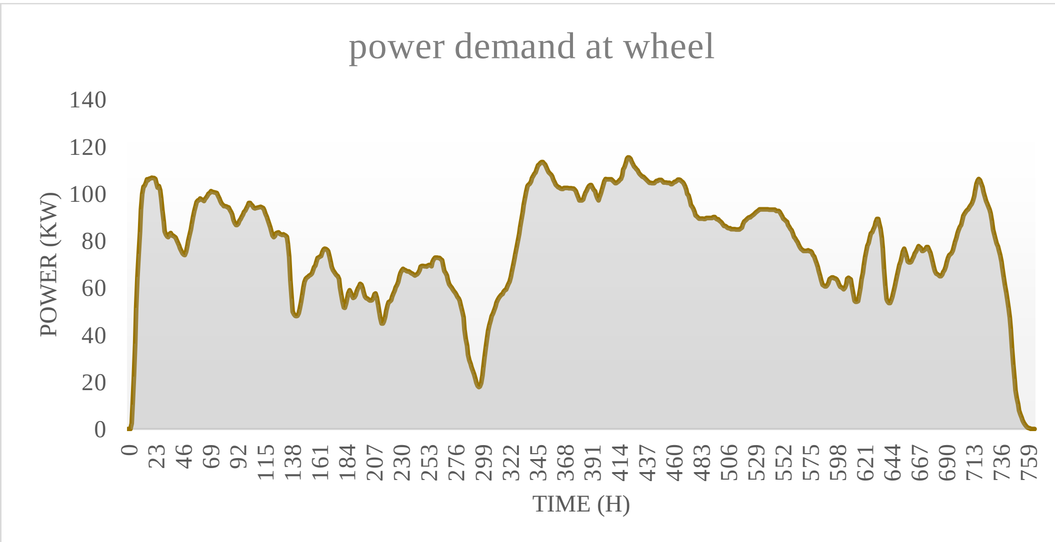


Figure 4-21. Driving cycle and power demand at the wheel

Assuming an ideal case, one the first day the fully charged EV batteries will provide 5250Wh of energy storage. On the next day, the second set of PV modules, which is mounted on the car roof, generates 445 W and the total weight of the modules is 18.6 kg. While driving the EV, the batteries will discharge and will recharge again using the onboard PV modules mounted on the EV. During driving, the EV may not be exposed to the sun or the weather maybe rainy or cloudy. For these reasons, the amount of energy generated by PV modules mounted on the EV will vary daily. I assume that the PV modules mounted on the EV charge the batteries for 0, 1, 2, 3, 4, or 5 hours daily. Adding these additional charges to fully charged batteries provides the EV with the total energy equal to 5250, 5695, 6140, 6585, 7030, and 7475 Wh, respectively. To keep the cost of PV-powered EVs low, we used lead-acid batteries in this analysis based on(Rydh, 2003). For more sophisticated battery model approach, (see(Alzuwayer et al., 2014)). The expected daily vehicle ranges are shown in Figure 4.23.

4.1.9.2 Intermediate Case Scenario

Here, the PV modules mounted on the EV are not cooled. The average temperature at this location is assumed approximately 35°C. Consequently, the PV modules mounted on the EV will provide less electrical power compared to onboard PV module in the best-case scenario. The new efficiency of these PV modules is equal to 12.5% with each generating around 250 W and the car batteries providing additional energy storage of 0, 250, 500, 750, 1000, and 1250 Wh for 0, 1, 2, 3, 4, or 5 hours per day respectively. The expected daily vehicle ranges as a function of vehicle speed are shown in Figure 4.23.

4.1.9.3 Worst Case Scenario

Here, the average temperature in both cases (home or if mounted on an EV) is assumed equal to 45 °C. The batteries charged at home provided less energy as compared to the previous cases. The modules will generate 625 W and the full day charged batteries would store 3125 Wh. The additional charge provided by the PV modules mounted to the the battery is identical to the intermediate case scenario. The expected daily vehicle ranges as a function of vehicle speed is in Figure 4.23.

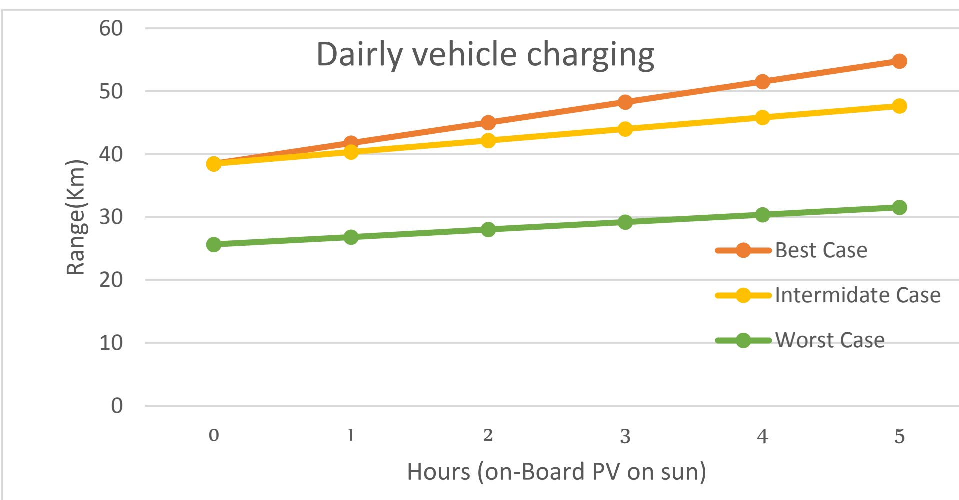


Figure 4-22. Daily vehicle charging hours (onboard PV on the sun)

4.2. Grid-connected PV systems with Electrical vehicles (off-board).

The result shows financial analysis, technical quality of the PV system, and system integration; - under financial analysis, the result is indicated in figure 4.24. In grid-connected PV systems with an electric vehicle or off-board listed below:- (1) financial analysis:- Return on assets is 19.8%, Revenue or saving 1688.4$/year and Accrued cash flow at end of the year (21) is equal to 26,045.81$, (2) Technical quality of the PV system:- total PV generated energy (AC grid) is equal to 8070 kWh/ year, the specific annual yield 1,371.07 kWh/kWp and the performance ratio (PR) is equal to 88.3%, and (3) system integration:-Energy from the grid is equal to 2,373 kWh per year and grid feed-in 4618 kWh/ year.

Financial Analysis		Tech. Quality of the PV System	
Return on Assets	19.18 %	PV Generator Energy (AC grid)	8,070 kWh/Year
Revenue or Savings	1688.4 $/Year	Spec. Annual Yield	1,371.07 kWh/kWp
Accrued Cash Flow (Cash Balance)	26,045.81 $	Performance Ratio (PR)	88.3 %

System integration			
Energy from Grid	2,373 kWh/Year	Grid Feed-in	4,618 kWh/Year

Figure 4-23. Grid-connected PV systems with electric vehicles highlight result

4.2.1 The Energy flow graph Grid-connected PV system with electrical vehicle

Figure 4.23 depicts a year's worth of energy flow. PV generates a total of 8070 kWh of electricity. 2,472 kWh for battery charging, 1,128 kWh for electric vehicle charging, 4,679 kWh for electric vehicle charging, 4,618 kWh for grid feeding, and 981 kWh for appliances were included in the total. In the worst-case scenario, if cloud, shadow, and inadequate for an electric vehicle, the grid's stored energy is used. In the case of form, 1,128 kWh of 4,618 kWh per year is used to charge an electric car, for a total of 3,600 kWh.

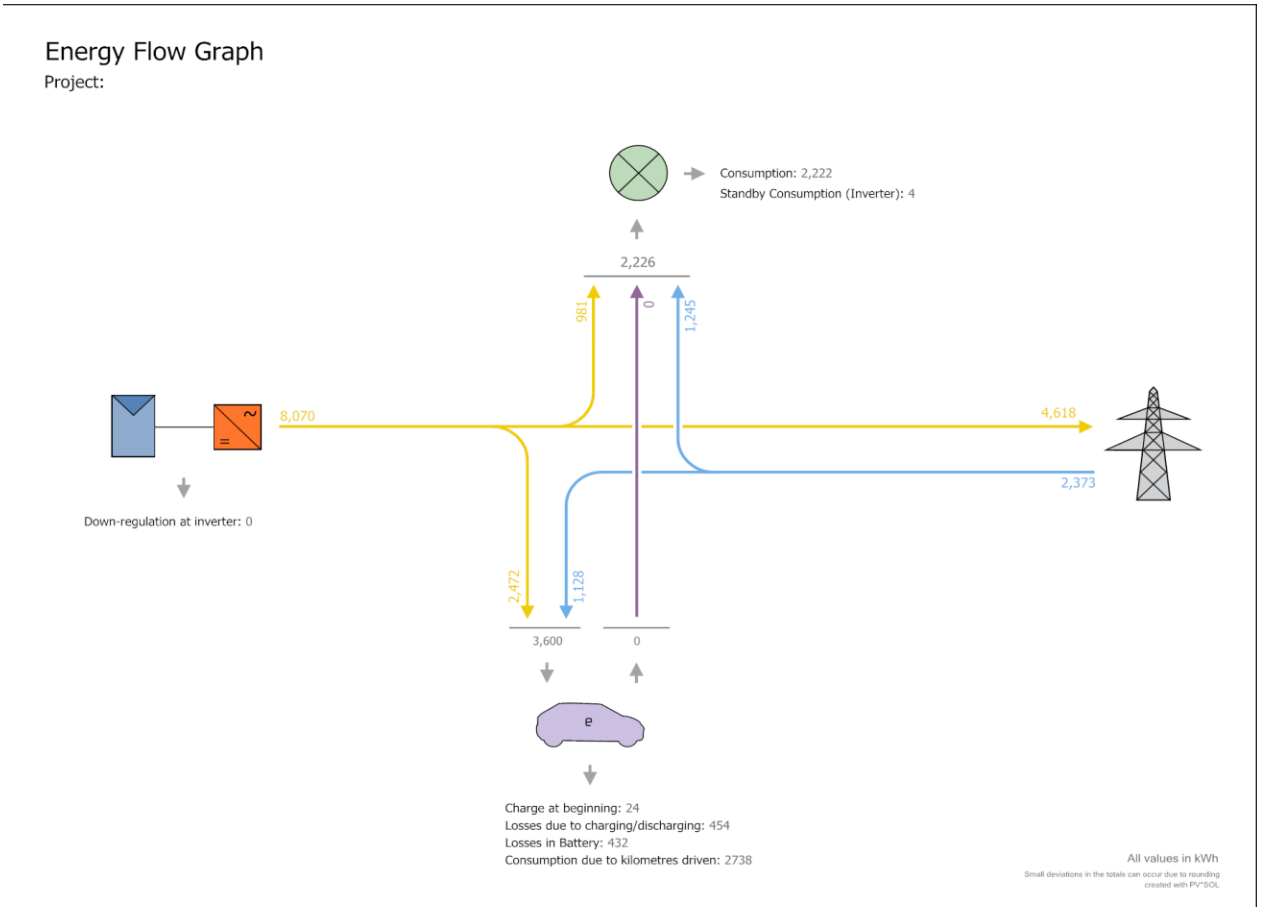


Figure 4-24. Energy flow graph

4.2.2. Energy production forest and consumption off- broad vehicle integrated of PV

PV generator energy (AC-grid) and grid from the grid have been used to produce energy, which will then be consumed by appliances, stand consumption (inverter), and charging of electric vehicles (Photovoltaic system), charging of electric vehicles (grid), and grid feed-in. The negative sign denoted energy consumption in several components, yet the energy production forest and consumption forest are balanced, or the sum is zero. Figure (4.25) shows the maximum and minimum energy output forecasts by PV generator energy (AC grid) for December 862.6 kWh and July 475.8 kWh, respectively. Annual energy production forecast by PV generator energy (AC-grid) is 8070.1 kWh, as well as energy from generator 2,373kWh, is produced and energy consumption by appliances is -2221.8 kWh, standby consumption (Inverter) is -3.8 kWh, the charge of the electric vehicle (PV system) is -2471.7 kWh, the charge of the electric vehicle (grid) is -1127.7 kWh and grid feed-in is -4617.6 kWh. Forest energy output is 10443.1 kWh, while consumption is 10442.5 kWh, a difference of less than 0.5 kWh.

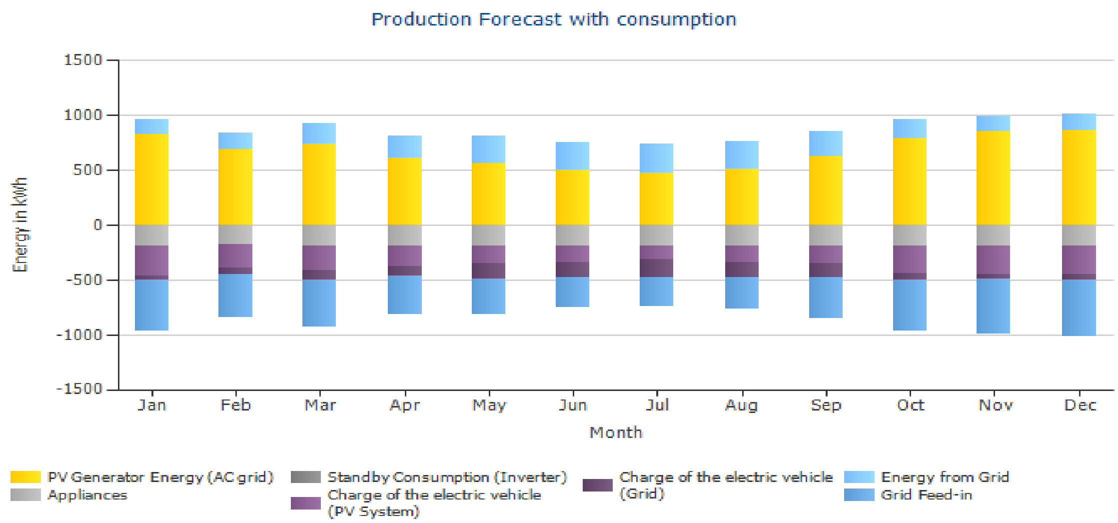


Figure 4-25. Production forecast with consumption

4.2.3 Use of PV Energy

PV generating energy (AC grid) is equivalent to the amount of energy used in direct own usage, grid feed-in, and charged of electric vehicle for each month, as illustrated in Figure 4.26. In January, PV Generator Energy (AC grid) was 829.2 kWh, with 84.2 kWh for direct personal usage, 470.5 kWh for grid feed-in, and 274.5 kWh for electric car charging.

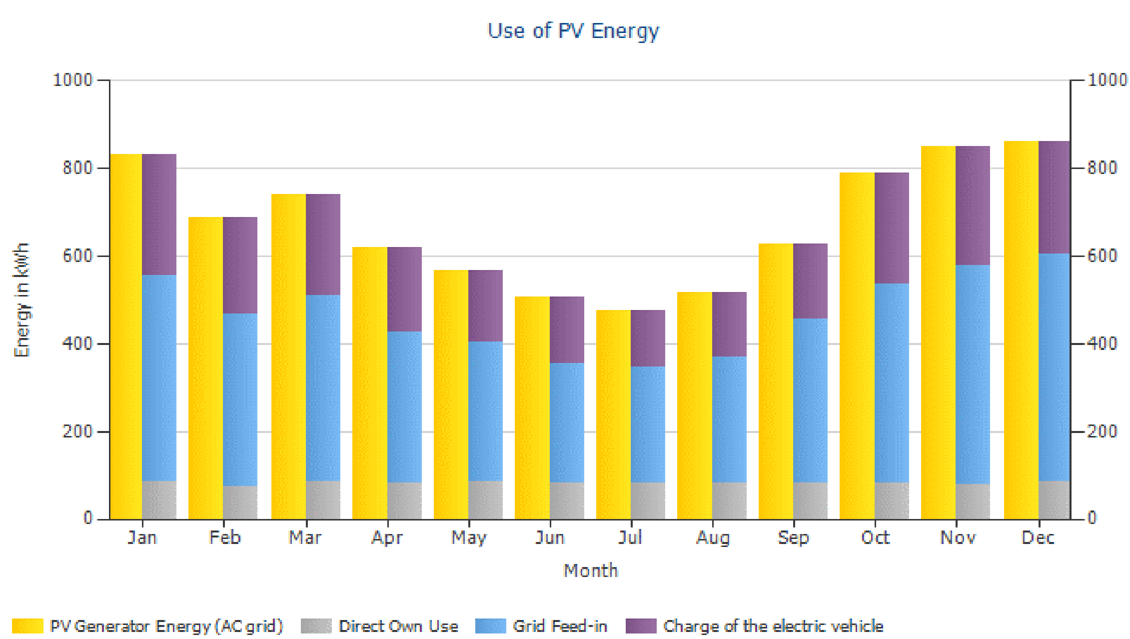


Figure 4-26. Use of PV Energy

4.2.4 Coverage of total consumption with Electric vehicle

Figure 4.27 Represents Electrical Appliances Consumption by different sources like PV, grid and battery. The total power needed for an electric appliance per month is 188.7 kWh. In January Month PV power supplies 358.7kWh, Charge of the electric vehicle (PV System) is 274.5 kWh, the charge of the electric vehicle(grid) is 33.8 kWh, stand consumption (Inverter) is 0.5 kWh.

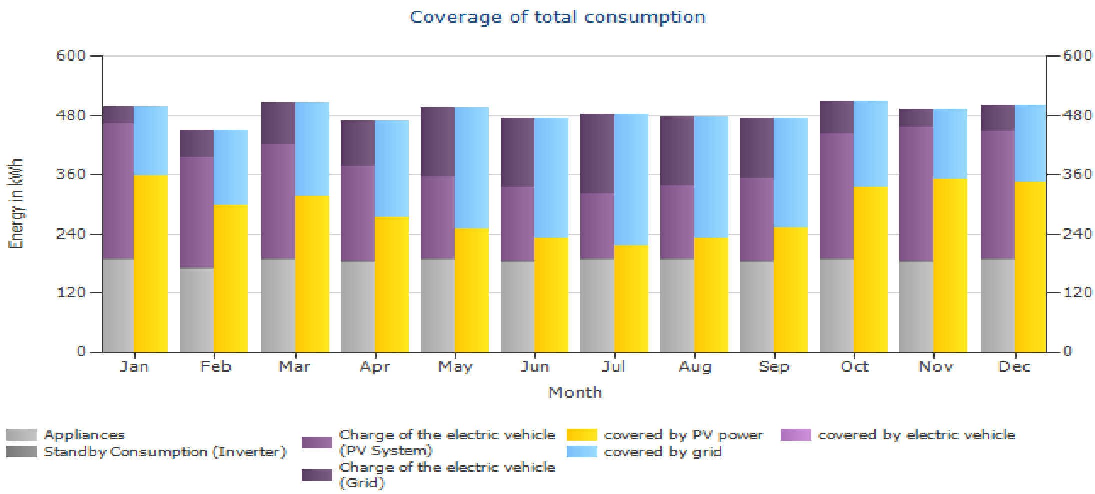


Figure 4-27. Coverage of total consumption

4.2.5 Production forecast per inverter

As discussed in Figure 4.28 production forecast per inverter PV generator energy (AC grid) per month is different the energy generator from January to July is gradually decreased and from August to December are increased.

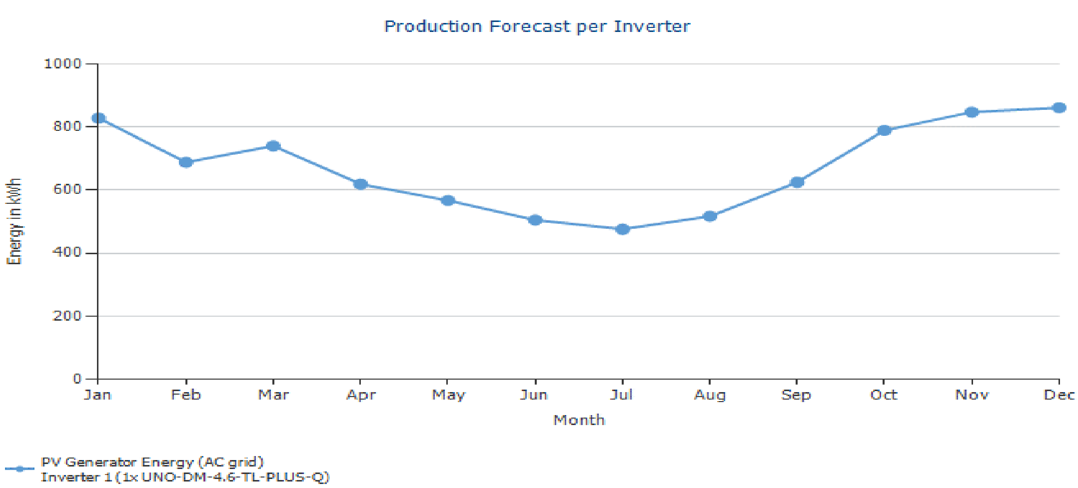


Figure 4-28. Production forecast per inverter

Figure 4.29 shows that the performance ratio per inverter per month is almost constant, which means the amount of energy or power converted by using an inverter when you determine in number the performance ratio of the inverter is between 87.63 % to 89.23 %.

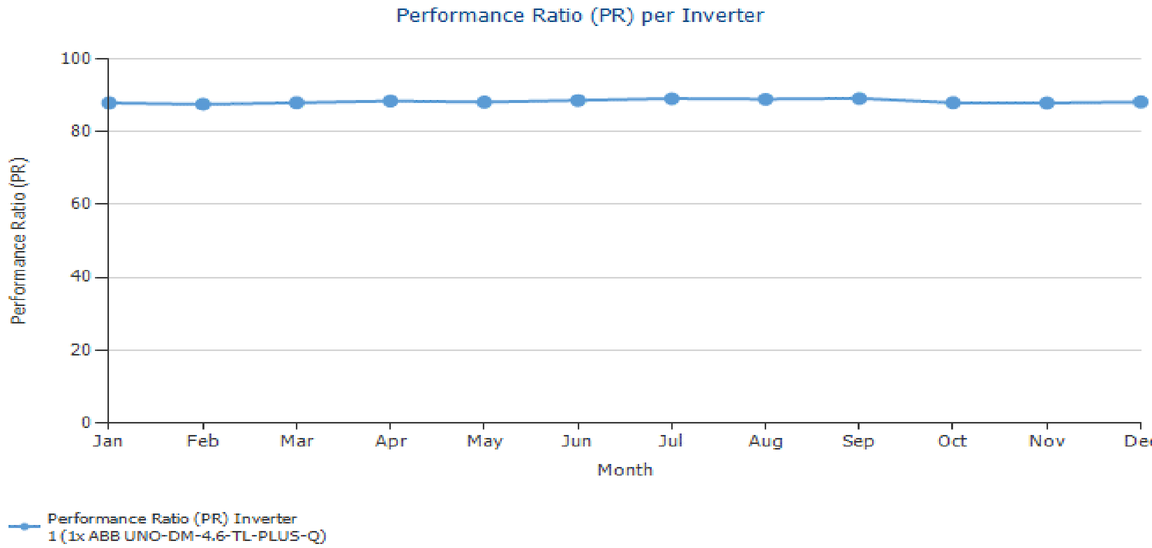


Figure 4-29. Performance ratio (PR) per Inverter

Table 4-4. Irradiance and Temperature

	Irradiance onto the horizontal plane (2,140.9 kWh/m²/Year)	Irradiance onto tilted surface Module Area 1 (1,550.7 kWh/m²/Year)	Outside Temperature	Module Temperature Module Area 1
Month	W/m²	W/m²	°C	°C
Jan	180	159.9	16.6	22.8
Feb	164.9	133.4	17.7	23.4
Mar	198.1	142.9	18.3	23.8
Apr	185.6	118.8	18.1	22.8
May	188.4	109.2	18.9	23.2
Jun	172.8	96.6	17.5	21.4
Jul	154.8	90.6	16	19.6
Aug	157	98.5	16.5	20.4
Sep	171.8	119	16.4	21.2
Oct	195.8	152.3	17.2	23.2
Nov	190.3	163.7	15.9	22.5
Dec	181.4	165.9	16.1	22.5

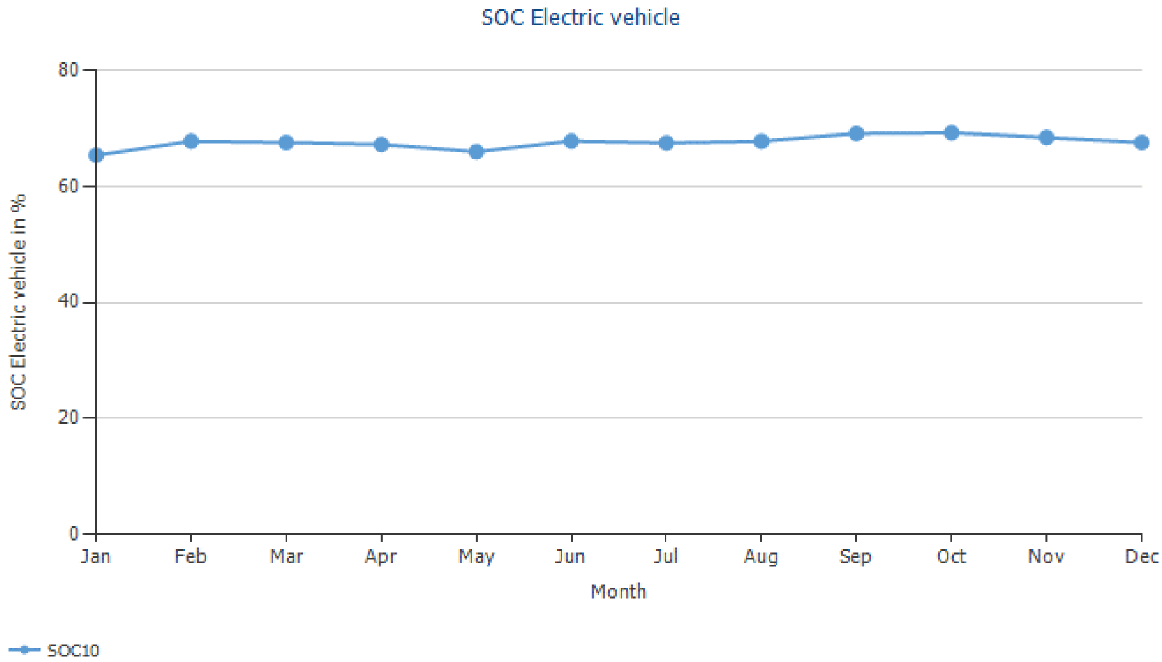


Figure 4-30. State of charging Electric vehicle

4.2.6 Energy Balance

Table 4-5. Energy Balance

Global radiation - horizontal	2,140.94	kWh/m²	
Deviation from standard spectrum	-21.41	kWh/m²	-1.00 %
Ground Reflection (Albedo)	28.40	kWh/m²	1.34 %
Orientation and inclination of the module surface	-80.27	kWh/m²	-3.74 %
Shading	-516.92	kWh/m²	-25.00 %
Reflection on the Module Interface	0.00	kWh/m²	0.00 %
Global Radiation at the Module	1,550.75	kWh/m²	
	1,550.75	kWh/m²	
	x 29.353	m²	
	= 45,518.91	kWh	
Global PV Radiation	45,518.91	kWh	
Soiling	0.00	kWh	0.00 %
STC Conversion (Rated Efficiency of Module 20.06 %)	-36,388.24	kWh	-79.94 %
Rated PV Energy	9,130.67	kWh	
Low-light performance	-220.84	kWh	-2.42 %
Deviation from the nominal module temperature	-340.27	kWh	-3.82 %

Diodes	-42.85	kWh	-0.50 %
Mismatch (Manufacturer Information)	-170.53	kWh	-2.00 %
Mismatch (Configuration/Shading)	0.00	kWh	0.00 %
PV Energy (DC) without inverter down-regulation	8,356.18	kWh	
Failing to reach the DC start output	-0.81	kWh	-0.01 %
Down-regulation on account of the MPP Voltage Range	0.00	kWh	0.00 %
Down-regulation on account of the max. DC Current	0.00	kWh	0.00 %
Down-regulation on account of the max. DC Power	-1.39	kWh	-0.02 %
Down-regulation on account of the max. AC Power/cos phi	0.00	kWh	0.00 %
MPP Matching	-43.42	kWh	-0.52 %
PV energy (DC)	8,310.55	kWh	
The energy at the Inverter Input	8,310.55	kWh	
Input voltage deviates from rated voltage	-9.58	kWh	-0.12 %
DC/AC Conversion	-230.85	kWh	-2.78 %
Standby Consumption (Inverter)	-3.87	kWh	-0.05 %
Total Cable Losses	0.00	kWh	0.00 %
PV energy (AC) minus standby use	8,066.25	kWh	
PV Generator Energy (AC grid)	8,070.12	kWh	

4.2.7 Financial Analysis

Figure 4.31. This shows that the total PV generator is 8070.3 kWh per year and the grid feed-in 4,618 kWh per annual. Energy from the grid is 1,128 kWh/year. The annual yield is 1371.07 kWh/kWp. Return on Assets is 19.18%. Accrued cash flow is calculated for 21 years. Investment amount, the export tariff for grid feed-in, Electricity savings, and annual cash flow are calculated for each year. At the end of 21 years, accrued cash is $ 26,045.8.

The proposed PV installations showed a short payback period of 5.3 years. This is shown in figure 4.31 which is a bar graph representing the payback cash flow where from zeroth year to the fifth year the bars are negative that represents the debt payment for the loan whereas from sixth to twenty-one year's bars are positive representing the profits.

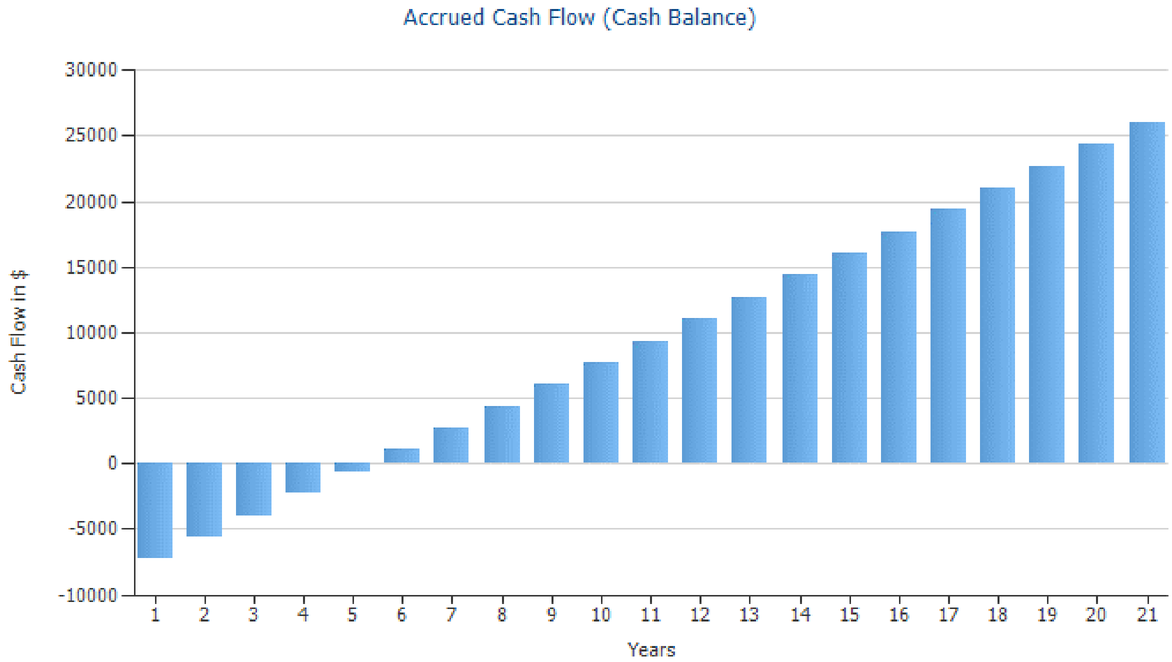


Figure 4-31. Accrued cash flow (cash balance)

Figure 4.32 represents the Electric cost before and after installation of PV. After PV installation Specific CO_2 saving through the use of PV energy is 470 g/kWh and the CO_2 emission avoided is 8701 Kg/Year

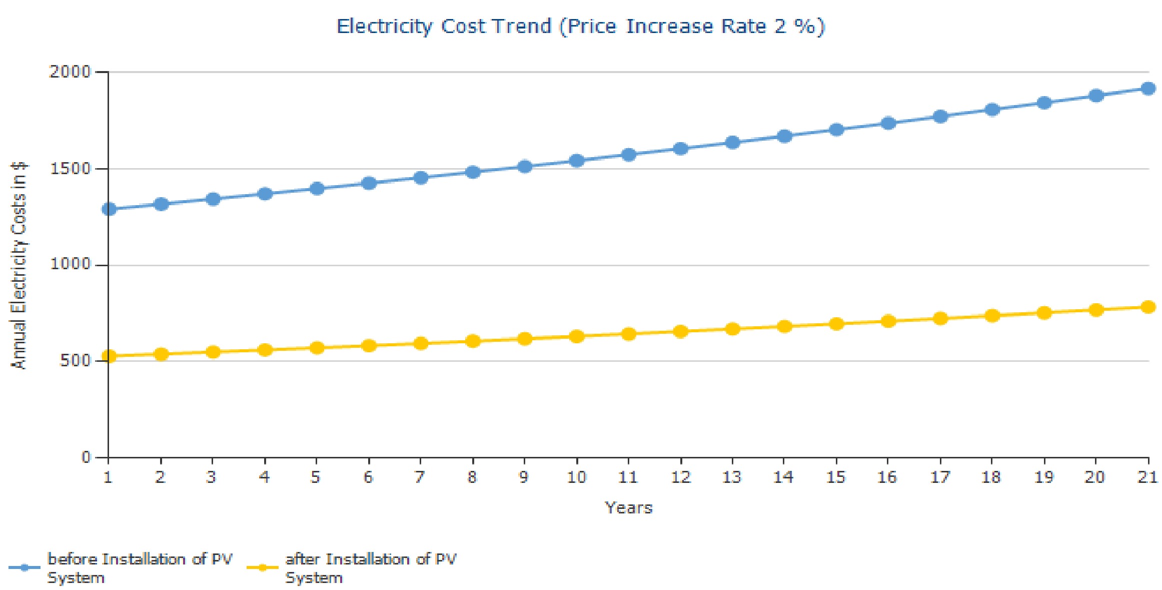


Figure 4-32.Electricity cost trend (price increase rate 2%).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

A life cycle assessment integrated on-board and off-board PV system model was developed for hybridizing with ICE, plug-in EV, and EV applications, and optimized for a solar energy-to-DC electrical power ratio (well-to-tank efficiency). In this paper, various design parameters as the PV device, the geographical solar location, thermal and electrical performances, MPPT algorithm, energy storage, tilt option, angling on the vehicle surface, and mounting configuration options were analyzed. Different driving scenarios was used to represent the driving conditions in Ethiopia at any time followed by Ethiopia assessment. In addition, eight different Nissan vehicle sizes (lightweight/aerodynamically efficient vehicle). When using Electric vehicle integrated off-board PV systems the similarly to onboard system. The Section PV sun power mono crystalline E20-327 based on functional requirements such as power density, specific weight, efficiency, life cycle cost for electricity, power temperature coefficient, and material concern (see detail examined in chapter two in Table 2: -1. Criteria selection of the type of PV panels), and the PV module are used with area 1.63 with the widths 1046mm and length is equal 1559mm detail expressed in figure 3.9. By considering design parameters, the maximum average daily energy storage using 3.26 m^2 PV module area is calculated as 4.465 kWh in February and 2.133 kWh in July. The maximum estimation of the extended pure PV solar range (PV range extender) for eight vehicles with different sizes indicated that the daily driving range could be extended from 3 miles to 22 miles based on vehicle specifications, locations, and time. The results showed that by adding on-board and off-board PVs to cover less and greater than 50% respectively of the projected horizontal surface area of a typical passenger EV, up to 50% of the total daily miles traveled by a person in Ethiopia. The results showed that the maximum energy stored in the battery with 3.26 m^2 PV modules in February is 4.465 kWh with an open rack mounting option. For a fair comparison between the two mounting options, the impacts on vehicle aerodynamics are analyzed. The roof rack option is reported to reduce the fuel economy by around 2% for a specific test vehicle (weight 1715kg with 2.8 m^2 frontal area). This test vehicle is close to my assumed vehicle 5, which has an energy efficiency of 368 Wh per mile (e.g., Nissan Leaf 2021), this means around 6 Wh more energy is consumed for every driven mile with roof rack option. Including the aerodynamic effect, the daily solar range extended for vehicle 5 in February in Ethiopia by 12 miles with the open rack option compared to 4 miles in the case of the insulated back option. However, future works are needed to test the aerodynamic impacts for specifically targeted vehicles.

When the vehicle was driven in a low solar energy location with an average electricity price is of $0.13/kWh and at today's PV system cost with integrated plug-in EV in July and in February, ROI was negative (-49.53) and was positive (398.26). Under the same price in a high solar environment, however, ROI was negative, around (-30.08%) and return on investment of adding onboard PV system with ICE, the vehicle in the low solar climate of Ethiopia in July, ROI had a negative value to positive value in a range of -50.86% to 66.61 % and Maximum ROI of adding onboard PV for different ICE vehicles is 42.76% to 252.27% in February with gasoline price is $/ gallon, return on investment of adding onboard PV system with EV, the vehicle in the low solar climate of Ethiopia in July, ROI had a negative value to positive value in the range of -24.42 % to 154.72 % and Maximum ROI of adding onboard PV for different EV vehicles is 69.12% to 438.58% in February depending upon the vehicle specifications, cost of investments, PV module cost, converter cost, battery cost, installation cost, and maintenance cost. The ROI sensitivity analysis, showed that for the very heavy vehicle (e.g., Nissan Armada) with 50% of vehicle time stay in the shade and drive in high solar energy location **s**till positive ROI is gained even if the low electricity price region. However, if the vehicle is driven in a low solar energy location with the same shade assumption, the ROI is positive only if the electricity price is high. Naturally, for all other vehicles with lesser weight, the ROI will be better for all scenarios. Like with any other solar application, the maximum EV is to stay at the sun the better benefit is gained. All these results are based on an average 12-year life cycle of the vehicle. However, the life of the PV module extends well beyond this time by as much as 20 years, meaning that it can be transferred into another application after the vehicle is recycled. Economic considerations of this transfer though were not examined in this research. In general cost analysis and Environmental impact of adding PV on-board vehicle with ICE, the simple payback is 4 years, greenhouse gas emission is 4 ton/year, the annual petroleum use is 7 barrels, and Annual air pollutants is the higher compare to others. In the case of plug-in EV and EV are the simple payback period is 3 and 2.5 years, annual greenhouse gas emission is less than 4 tons/year and greater than 2 tons/year, and annual petroleum use 5 barrels and less than 1 barrel respectively.

In Grid-connected PV systems with Electrical vehicles (off-board) the result shown financial analysis, technical quality of the PV system, and system integration; - under financial analysis, the result in grid-connected PV systems with an electric vehicle or off-board listed below:- (1) financial analysis:- Return on assets is 19.8%, Revenue or saving 1688.4$/year and Accrued cash flow at end of the year (21) is equal to 26,045.81$, (2) Technical quality of the PV system:- total PV generated energy (AC grid) is equal to 8070 kWh/ year, the specific annual yield 1,371.07 kWh/kWp and the performance ratio (PR) is equal to 88.3%, and (3) system integration:-Energy from the grid is equal to 2,373 kWh per year and grid feed-in 4618 kWh/ year. Accrued cash flow is calculated for 21 years. Return on investment, the export tariff for grid feed-in, Electricity savings, and annual cash flow are calculated for each year. At the end of 21 years, accrued cash is $ 26,045.8. The proposed PV installations showed a short payback period of 5.3 years. The payback cash flow where from zero years to the fifth year the bars are negative that represents the debt payment for the loan whereas from sixth to twenty-one years bars are positive representing the profits.

5.2 Recommendations

The recommendation here is to deal with uncertainty as below: This study focuses only on WTW analyses are divided into two stages: the fuel production is studied in the well-to-tank (WTT) stage, and the vehicle operation is analyzed in the tank-to-wheel (TTW) stage. Further research on Life cycle assessment of vehicle integrated to PV (Cradle to gate). I suggested that future research presented a series of design requirements and promising results for the implementation of onboard PV in automobiles. This work also optimized the solar energy to the DC electrical power ratio for this application. However, there is a need to go to the product level and implement this proposed system for a specific vehicle under a specific scenario. For example, there is a need to implement a sophisticated control strategy for specific vehicles to optimize the use of available solar energy. This includes maximizing the use of solar energy directly to the wheels and eliminates the energy stored in the battery to eliminate any losses in the battery (e.g., charging efficiency and discharging efficiency). The engine operating points, battery SOC, and driving patterns must also be considered. In addition, when a vehicle is parked, if there is no window to store the DC electricity in the onboard battery, the extra energy can be returned to the grid (e.g., vehicle to grid integration).

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APPENDIX

Appendix -1

Table 1 total energy stored in battery proposed PV module system

Month	Hourly 7-8 am	Hourly 1-2 pm	Hourly 5-6 pm	Daily
Minimum scenario Dec	20Wh	295Wh	115Wh	2.133 kWh
Maximum scenario Feb	75 Wh	517 Wh	302 Wh	4.465 kWh

Appendix -2

Table 2 Total cost of investment for enter VIPV solar powertrain

Components	Quantity	Current price ($)	Future price ($)	Notes
PV Module	654W	616	350	
Battery	5 kWh	2525	1525	
Motor and Controller	10 kWh	642	642	
Total		3783	2517	

Appendix -3

Table -3 Assumptions for EV with PV

PV Module SUNPOWER Model: Mono -Si E20-327	Specifications at 25 ºC, Specific weight=17.58 W/kg Density=185.2 W/m^2, PTC=-0.38%/ºC Efficiency=20.4%. Total weight of on-board PV with support structure= 23.6.kg Area of on-board PV=2 m^2 (the constraint is the available installation area on the vehicle the best-case scenario)
Assumptions for scenarios	Best scenario: The temperature in both on-board & off-board PV modules at STC (25 ºC) Intermediate scenario: Onboard PV module at (45°C) & off-board PV modules at STC (25 ºC) Worst scenario: The temperature in both on-board & off-board PV modules at 45 ºC
PV Module Configuration	Horizontal
Operating Location	Insolation = 5.25 $kWh/m^2/day$ (Average in Ethiopia)
Typical Lead-acid Batter	Specific energy=40 Wh/kg Capacity=7 kWh, Operating window of the battery state of charge (SOC) >20% & < 80% Batteries weight= 175 kg
Typical lightweight Vehicle Specifications	Traction efficiency (η)=0.8 Drag coefficient (Cd) X frontal area (Af)=0.5 Air density (ρ) = 1.225 kg/m^3 Coefficient of rolling resistance (Cr) = 0.008 Gravitational constant=9.81 m/s^2 Total weight (M)=curb weight + PV weight + driver=668 kg

Appendix -4

Calculation of Vehicle Drag Coefficient and Coefficient of Rolling Resistance

time	V1	V2	V3	V4	V5	V6	V avg
	Trials in Direction 1			Trials in Direction 2			
sec	kph	kph	kph	kph	kph	kph	kph
0	70	70	70	70	70	70	70.0
10	61	60	60	60	61	60	60.3
20	52	52	51	51	52	51	51.5
30	44	44	43	43	43	44	43.5
40	37	37	38	37	37	37.5	37.3
50		32	32		32.5	32	32.1
60		27			27.5	27	27.2
70		22			22.5		22.3

rho	1.22	kg/m^3	density of air (adjust for your altitude)
g	9.81	m/s^2	gravitational constant
A	2.3	m^2	frontal area
M	1000	kg	mass of vehicle plus occupants

time	V actual	V model	F	a	Error^2
sec	m/s	m/s	Newtons	m/s^2	
0	19.44	19.44	299.8021	0.299802	0.00000
5		17.94543	270.7322	0.270732	
10	16.76	16.59177	246.4836	0.246484	0.02805
15		15.35935	226.0603	0.22606	
20	14.31	14.22905	208.7143	0.208714	0.00585
25		13.18548	193.8758	0.193876	
30	12.08	12.2161	181.1044	0.181104	0.01763
35		11.31058	170.0549	0.170055	
40	10.35	10.46031	160.4536	0.160454	0.01279
45		9.658036	152.0824	0.152082	
50	8.92	8.897624	144.7641	0.144764	0.00068
55		8.173804	138.3552	0.138355	
60	7.55	7.482028	132.7379	0.132738	0.00413
65		6.818339	127.8153	0.127815	
70	6.18	6.179262	123.507	0.123507	0.00000

Sum of Error^2 (minimise by changing Cd and Crr) **0.06913**

Drag coefficient	Cd =	0.369681
Coefficient of rolling resistance	Crr =	0.010571

Appendix- 5

Calculation of the solar PV energy ouput of a photovoltaic system

(yellow)	Yelow cell = enter your own data
(green)	Green cell = result (do not change the value)
(white)	White cell = calculated value (do not change the value)

Global formula : **E = A * r * H * PR**

E = Energy (kWh)	1086	kWh/an
A = Total solar panel Area (m²)	3.26	m²
r = solar panel yield (%)	20%	
H = Annual average irradiation on tilted panels (shadings not included)*	2222.85	kWh/m².an
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75	
Total power of the system	0.7	kWp

Losses details (depend of site, technology, and sizing of the system)

- Inverter losses (6% to 15 %)	8%
- Température losses (5% to 15%)	8%
- DC cables losses (1 to 3 %)	2%
- AC cables losses (1 to 3 %)	2%
- Shadings 0 % to 40% (depends of site)	3%
- Losses weak irradiation 3% yo 7%	3%
- Losses due to dust, snow... (2%)	2%
- Other Losses	0%

Appendix -6

Table:4 - Accrued cash flow (cash Balance)

Years	-
1	-7279.45986665746
2	-5609.29197212622
3	-3940.51524373313
4	-2272.96595557932
5	-606.480634586301
6	1059.10456314294
7	2723.95230333412
8	4388.2268374464
9	6052.09033475898
10	7715.70700983314
11	9379.23881873794
12	11042.8495103969
13	12706.7024290134
14	14370.9604181284
15	16035.7863869309
16	17701.3431949501
17	19367.7948323777
18	21035.3037034051
19	22704.0337394563
20	24374.1483430797
21	26045.8109130214

Appendix -7. A-Return on Investment of adding on-board with Plug-in EV

Type of vehicle	Gain on Wh/m	max in F	min in Ju	cost cost Plug -i	GOI Max	Min	Plug-in COI		ROI Max	ROI min
2021 NISSAN370Z	328	14	4	13	2363.15	694.39	$1,226.40		$92.69	-43.38
2021 Nissan Altima	364	12	4	13	1918.83	625.71	$1,226.40		$56.46	-48.98
2021 Nissan Maxima	343	13	4	13	2160.98	664.02	$1,226.40		$76.21	-45.86
2021 Nissan Armada 4WD	205	22	10	13	6110.63	2890.02	$1,226.40		$398.26	135.65
2021 Nissan Leaf	368	12	4	13	1877.34	618.91	$1,226.40		$53.08	-49.53
2021 Nissan Kick	332	13	5	13	2306.55	857.53	$1,226.40		$88.07	-30.08
2021 Nissan Sentra	338	13	5	13	2225.39	842.31	$1,226.40		$81.46	-31.32
2021 Nissan NV200 Cardo	349	13	4	13	2087.32	652.61	$1,226.40		$70.20	-46.79

Appendix -7. B-Return on Investment of adding on-board with ICE

Type of vehicle	GOI MPG	max in	min i	cost Cost (	GOI Max	Min	ICE COI	ROI Max	ROI min
2021 NISSAN370Z	46.19	14	4	6	7745.12	2275.83	$4,340.40	78.44	-47.57
2021 Nissan Altima	49.29	12	4	6	6540.49	2132.80	$4,340.40	50.69	-50.86
2021 Nissan Maxima	40.19	13	4	6	8513.04	2615.88	$4,340.40	96.13	-39.73
2021 Nissan Armada	37.81	22	10	6	15289.96	7231.37	$4,340.40	252.27	66.61
2021 Nissan Leaf	38.69	12	4	6	8241.88	2717.14	$4,340.40	89.89	-37.40
2021 Nissan Kick	57.02	13	5	6	6198.72	2304.56	$4,340.40	42.81	-46.90
2021 Nissan Sentra	56.03	13	5	6	6196.36	2345.32	$4,340.40	42.76	-45.97
2021 Nissan NV200	43.32	13	4	6	7761.65	2426.71	$4,340.40	78.82	-44.09

Appendix -7. C-Return on Investment of adding on-board with EV

Type of vehicle	GOI Wh/m	max in	min	cost cost E	GOI Max	Min	EV COI	ROI Max	ROI min
2021 NISSAN370Z	328	14	4	13	2363.15	694.39	$1,134.59	$108.28	-38.80
2021 Nissan Altima	364	12	4	13	1918.83	625.71	$1,134.59	$69.12	-44.85
2021 Nissan Maxima	343	13	4	13	2160.98	664.02	$1,134.59	$90.46	-41.47
2021 Nissan Armada	205	22	10	13	6110.63	2890.02	$1,134.59	$438.58	154.72
2021 Nissan Leaf	368	12	4	13	1877.34	618.91	$1,134.59	$65.46	-45.45
2021 Nissan Kick	332	13	5	13	2306.55	857.53	$1,134.59	$103.29	-24.42
2021 Nissan Sentra	338	13	5	13	2225.39	842.31	$1,134.59	$96.14	-25.76
2021 Nissan NV200 (	349	13	4	13	2087.32	652.61	$1,134.59	$83.97	-42.48

Appendix -7. D- Daily pure range

added PV @ 7-8 Am		added PV @1-2 Pm		Added PV @5-6 Pm											
MPG PV	MPG PV														
min	max	Min	Max	Min	Max	VEHICLE efficir	power(kW	gas/Ele	city	Highway	combined	Range(mil	Annual fuel cost	Cost to Drive 25 Miles	co2(gram/m
69.76	72.14	73.76	77.86	70.74	73.81	67	248	5.gal/100mil	17	26	20	400	$2,450	$4.08	445
68.31	70.58	72.13	76.05	69.24	72.18	73	136	3.1	28	29	32	518	$1,250	$2.05	281
63.47	65.43	66.76	70.10	64.28	66.80	64	224	4.2	20	30	24	432	$2,050	$3.40	370
38.06	38.75	39.22	40.35	38.35	39.22	23	298	6.7	13	18	15	400	$3,250	$5.43	594
60.13	61.89	63.08	66.05	60.86	63.11	65	110	30kWh/100m	123	99	111	149	$600	$0.99	0
77.03	79.93	81.93	87.01	78.22	82.00	75	93	3.gal/100mil	31	36	33	400	$1,200	$1.99	269
75.67	78.47	80.40	85.29	76.82	80.46	75	111	3	29	39	33	409	$1,200	$1.99	268
65.38	67.46	68.88	72.43	66.24	68.91	67	98	4	24	26	25	400	$1,600	$2.63	300

Appendix -8-

		Total daily Energy (Wh)stored in battery							battery		EPV @Wheel in city		EPV @Wheel in High	
	Feb	July	A	Feb	July	Feb	July	hour	July	Feb	July	Feb	July	Feb
20%	6847	3271	3.261	4465.613	2133.346	4465	2133	5-6pm	20	75	6.84	25.65	3.825	14.34375
25%			3.261	5582.017	2666.683	5582	2666	1-2 pm	295	517	100.89	176.814	56.41875	98.87625
30%			3.261	6698.42	3200.019	6698	3200	17-18	115	302	39.33	103.284	21.99375	57.7575

$$E_{PV\,at\,wheel} = T_{Cycles} \times \eta_{PV2W} \times E_{PV-hourly}$$

daily Energy (Wh) stored on battery

Appendix- 9

Normal power before PV added

	Type of vehicle	Cd	Cr	Af (m2)	MV (Kg)	Fd (N)	Fr (N)	Pd (N)	Pr (N)	Pt (W)
1	2021 NISSAN370Z	0.3	0.008	2.4	1466	46.42	115.05	476.3	1180.43	1656.73
2	2021 Nissan Altima	0.26	0.008	2.6	1517	43.58	119.05	447.2	1221.496	1668.69
3	2021 Nissan Maxima	0.29	0.008	2.6	1622	48.62	127.23	498.8	1306.042	1804.83
4	2021 Nissan Armada 4WD	0.31	0.008	3.9	2708	77.96	212.52	799.79	2180.495	2980.29
5	2021 Nissan Leaf	0.28	0.008	2.8	1715	50.55	134.6	518.64	1380.926	1899.57
6	2021 Nissan Kick	0.34	0.008	2.8	1224	62.10	96.06	637.19	985.5707	1622.75
7	2021 Nissan Sentra	0.26	0.008	2.6	1349	43.59	105.87	447.2	1086.221	1533.41
8	2021 Nissan NV200 Cardo VA	0.31	0.008	3.2	1487	63.96	116.7	656.23	1197.34	1853.56

Power loss after PVs added

Type of vehicle	Cd	Cr	Af (m2)	MV (Kg)	Fd (N)	Fr (N)	PD (N)	Pr (N)	Pt (W)
2021 NISSAN370Z	0.3	0.008	2.66	1596	51.45	125.25	527.9	1285.1	1813.01
2021 Nissan Altima	0.26	0.008	2.81	1647	47.10	129.26	483.31	1326.1	1809.4
2021 Nissan Maxima	0.29	0.008	2.8	1752	52.36	137.45	537.16	1410.71	1947.88
2021 Nissan Armada 4WD	0.31	0.008	4.1	2838	81.95	222.72	840.8	2285.17	3125.98
2021 Nissan Leaf	0.28	0.008	3.01	1845	54.34	144.79	557.53	1485.60	2043.14
2021 Nissan Kick	0.34	0.008	3.01	1354	66.76	106.26	684.98	1090.24	1775.22
2021 Nissan Sentra	0.26	0.008	2.81	1479	47.10	116.07	483.31	1190.89	1674.21
2021 Nissan NV200 Cardo VA	0.31	0.008	3.4	1617	67.96	126.9	697.25	1302.01	1999.26