Off-Grid Rooftop PV Power Plant Design for a Duplex Apartment on PV*SOL

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ATU-ADANA

01.06.2020

Introduction

- The aim of this project work is to simulate an off-grid rooftop PV power plant for a duplex apartment in the following coordinates:

Longitude	Latitude
37.50404415	35.86275261

Table 1: Coordinates of Duplex Apartment

This design will be done in two different ways:

- Manual calculation with block diagram that illustrates methodology of design which we have learned in the scope of EEE407.
- on PV*SOL 5.5(R2)

Location

- Coordinates show this address: Gedikli-Kozan/Adana/Turkey

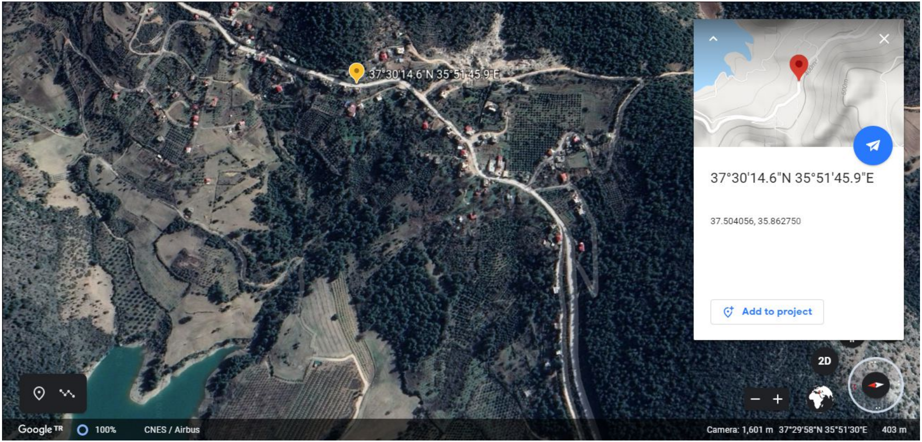


Figure 1: Location on Google Earth

The Duplex Apartment

- One person lives in this duplex apartment.
- Surface area belonging to the duplex apartment is 60 square meters.

Number of rooms:

- a hall
- a bedroom
- a guestroom
- a kitchen
- a cellar
- a bathroom and an en-suite bathroom

The Duplex Apartment

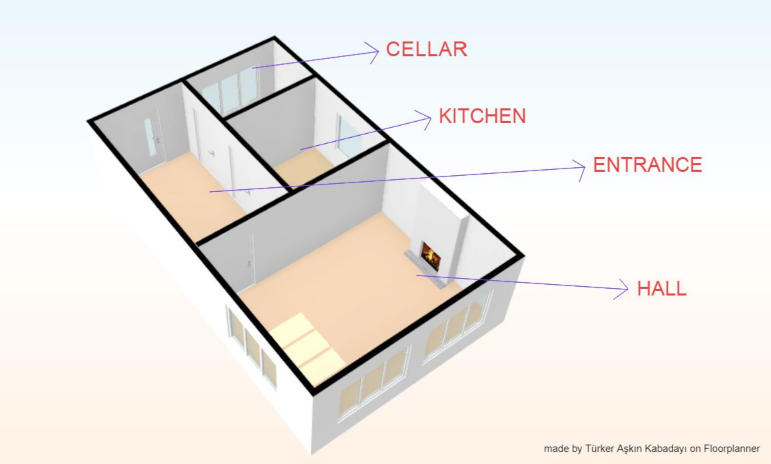


Figure 2: First Floor of the Duplex Apartment

The Duplex Apartment

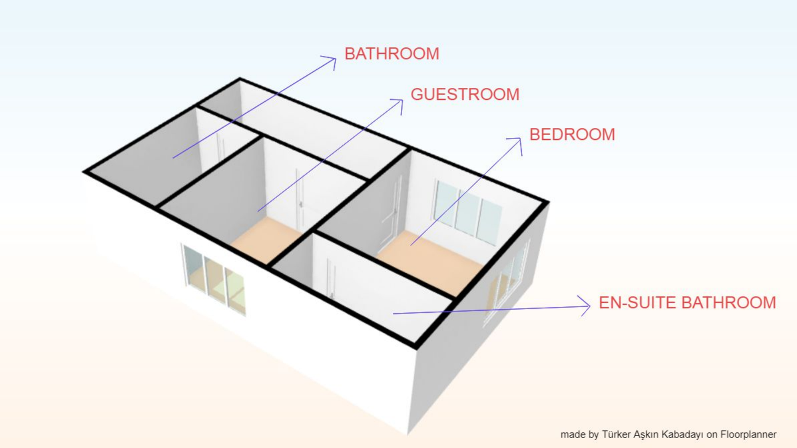


Figure 3: Second Floor of the Duplex Apartment

Climate Data

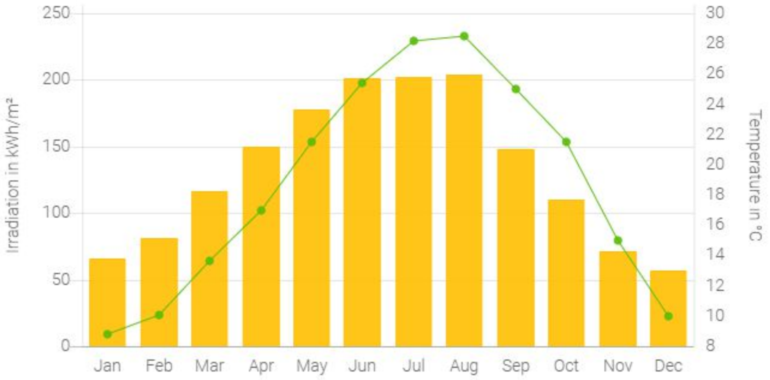


Figure 4: Climate Data during a Year

Climate Data

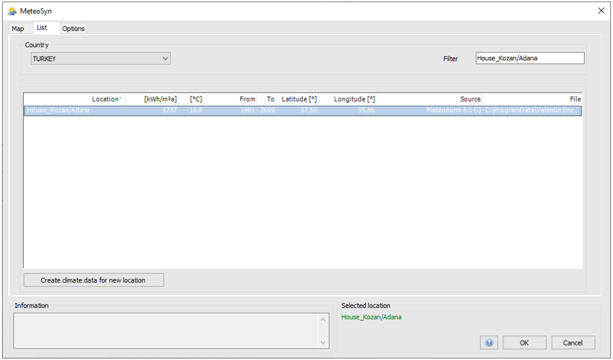


Figure 5: Average Climate Data per Year

Climate Data

Irradiation in kWh/m^2	1737
Avg. Temperature [$^\circ C$]	18.8

Table 2: Average Climate Data per Year

*Climate datas PV * SOL 5.5 (R2) software and http://pvsol-online.valentin-software.com/ belongs to the site.*

Climate Data

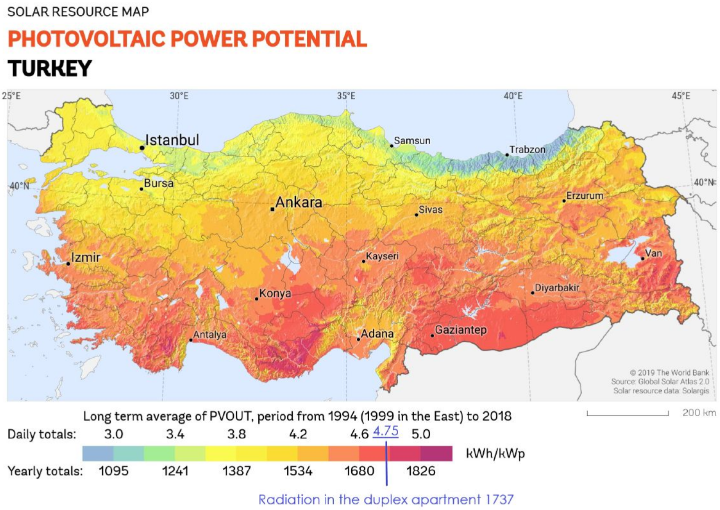


Figure 6: Insolation Map of Turkey

Manual Calculation

In this section manual calculations with block diagram showing the design methodology will be applied.

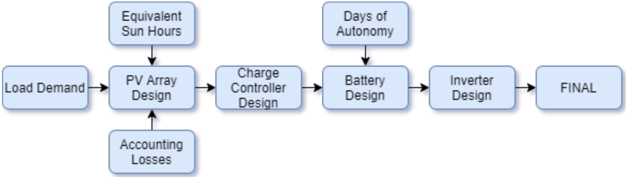


Figure 7: Block Diagram of Design Methodology

Manual Calculation

Equipment

- Inverter Efficiency=0.98
- Battery System=0.90
- PV Module Characteristics:

P (W_p)	$V_{mpp}\,(V)$	$I_{mpp}\,(A)$	$V_{oc}\,(V)$	$I_{sc}\,(A)$
300	36.7	8.17	43.6	8.71

- MPPT Charge Controller Specifications:

$V_{max}\,(V)$	$I_{max}\,(A)$	$V_{operational}\,(V)$
150	40	12/24

- Battery Features:

DoD (%)	$V_{battery}\,(V)$	$C_{battery}\,(Ah)$
70	12	180

Load demand is the first element of the system and is very important. Because if it is analyzed incorrectly, missing or more panels can be used in the system.

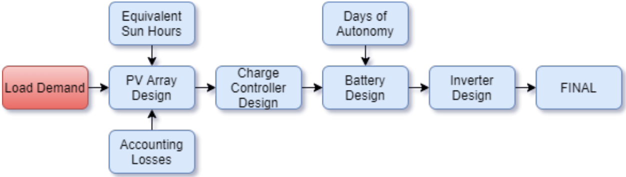


Figure 8: Step of Design Methodology

Manual Calculation

Load Demand

Electrical Needs of the House					
Item	**Type**	**Quantity**	**Power per Item (W)**	**Time of Use per Day(**	**Consumption (kWh/Day)**
Washing Machine	AC	1	500	1	0.5
Deep Freezer	AC	1	19	24	0.456
Laptop Computer	AC	1	50	2	0.1
Dishwasher	AC	1	1200	1	1.2
Domestic Water Pump	AC	1	200	1	0.2
Refrigerator	AC	1	100	24	2.4
Air Conditioner 12.000 Btu A+++	AC	1	1000	3	3
Philips Hue Smart Bulb	AC	10	8	7	0.56
Electric Oven	AC	1	1550	1	1.55
49 Inch LED TV	AC	1	85	2	0.17
Apple TV	AC	1	3	1	0.003
Xbox One	AC	1	50	1	0.05
Phone Charger	AC	1	4	1	0.004
Power consumption datas belong to daftlogic.com				**TOTAL**	**10.193**
//				**AC POWER (kW)**	**4841**
Designed by Türker Aşkın Kabadayı on Microsoft Excel				**DC POWER (kW)**	**0**

Figure 9: Electrical needs of the duplex apartment

Formula-Consumption per Item

Consumption per Item $= Quantity \times Power\ per\ Item \times Time\ of\ Use$

Example-Consumption of Refrigerator

$1 \times 100\ W \times 24\ h/day = 2.4\ kWh/day$

Total Consumption $= 10.193\ kWh/day$

Equivalent Sun Hours=4.75 hours

Accounting Losses are ignored

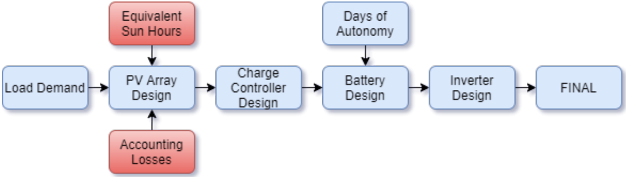


Figure 10: Step of Design Methodology

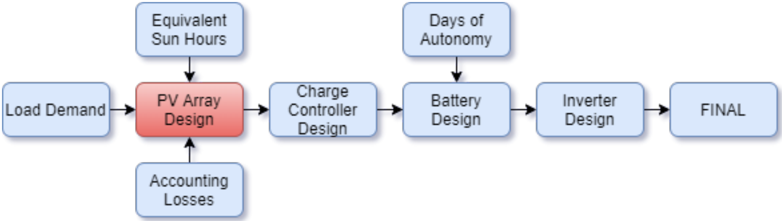


Figure 11: Step of Design Methodology

Selection:Polycrystalline Solar Cell

Polycrystalline solar panel can be called a full market product. It is balanced in terms of both efficiency and unit cost and it is the cheapest solar panel. Many solar power plants are built with polycrystalline solar panels.
Almost 68 percent of the market uses polycrystalline solar cells. Also, it is not affected by the temperature changes in the air.
The efficiency rates of these solar cells are around 15 percent.

The main reason for choosing a polycrystalline solar cell is that Adana's climate (dust and hot weather) and its low-cost.

This data belongs to the website of Ayges Technology Company.

Manufacturer:Chinaland Solar Energy Co., Ltd.

Model:CHN300-72P

Rated Max. Power (P_{max})	300 W
Max. Power Voltage (V_{mp})	36.7 V
Max. Power Current (I_{mp})	8.17 A
Open Circuit Voltage (V_{oc})	43.6 V
Short Circuit Current (I_{sc})	8.71 A

Table 3: Parameters of PV Panel

Manual Calculation
PV Panels Design

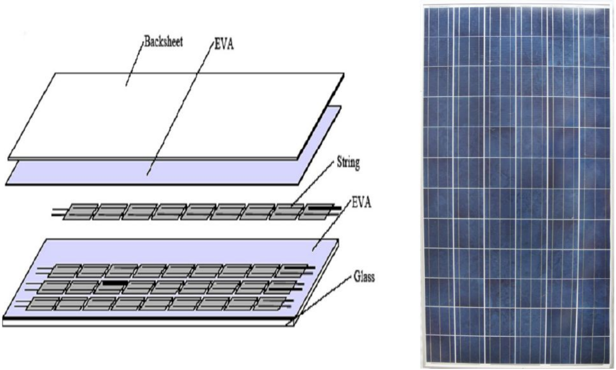


Figure 12: CHN300-72P

Manual Calculation

PV Panels Design

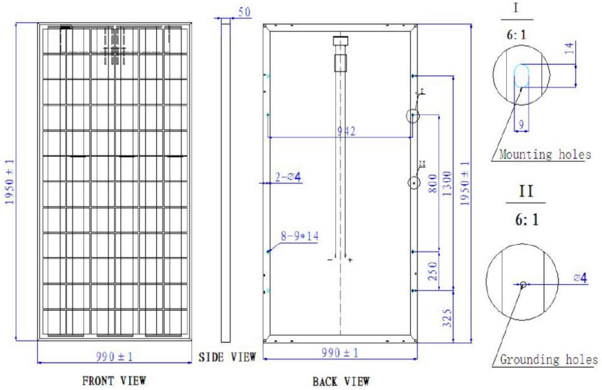


Figure 13: Dimensional Characteristics

Manual Calculation

PV Panels Design

$$E_{total} = (10.193\, kWh/day)/(0.98 \times 0.90) = 11.556\, kWh/day$$

$$\text{Minimum } W_p = (11.556\, kWh/day)/(4.75\, h/day) = 2.433\, kW$$

Numbers of Panels =2.433 kW/300 W =8.11=9 Panels

Parallel

Maximum Current I_{max} =8.71 A×3 $= 26.13\,A$ (smaller than 40 A)

Series

Maximum Voltage V_{max} =43.6 V×3 $= 130.8\,V$ (smaller than 150 V)

Panels will be install in 3 parallel sticks consisting of 3 series panels.

Configuration=3×3

Manual Calculation

Charge Controller Design

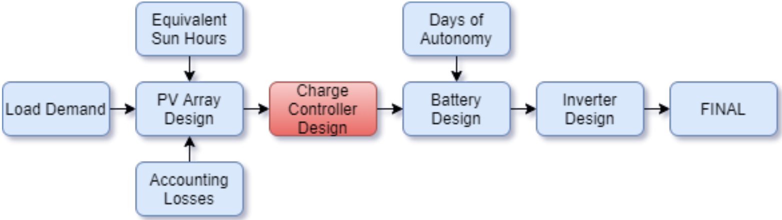


Figure 14: Step of Design Methodology

Manufacturer:Epever

Model:4215BN

$V_{max}(V)$	150V
$I_{max}(A)$	40A
$V_{operational}(V)$	12/24V

Table 4: MPPT Charge Controller Specifications

Figure 15: 4215BN

Days of Autonomy=2

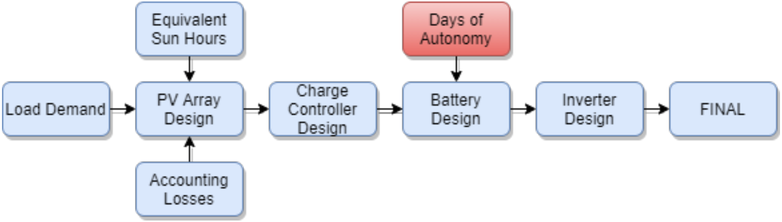


Figure 16: Step of Design Methodology

Manual Calculation

Battery Design

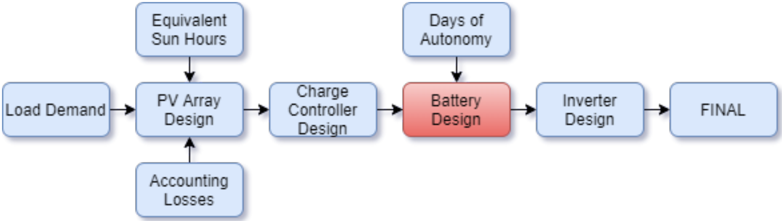


Figure 17: Step of Design Methodology

Manual Calculation

Battery Design

Manufacturer:DETA

Model:12VSolar190

DoD(%)	70
$V_{battery}$	12V
$C_{battery}$	180Ah

Figure 18: 12VSolar190

Minimum $C_{battery} = (11.556\,kWh/day/(0.7 \times 24)) \times 2 = 1375.71\,Ah$

Num. of batt. in series=24 V/12 V=2 batteries

Num. of batt. in parallel=1375.71 Ah/180 Ah=7.64=8 batteries

$$2\times8 = 16\,Batteries$$

Manual Calculation

Inverter Design

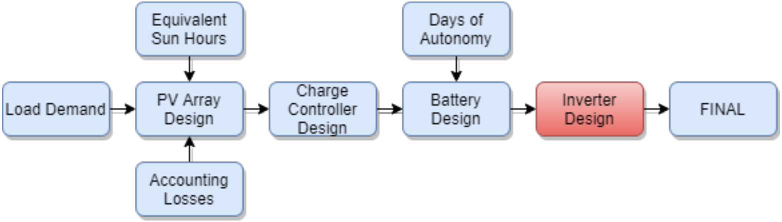


Figure 19: Step of Design Methodology

Manufacturer:Essen Solar

Model:FSP302PV-230F-24

Efficiency	98%
Opr. Voltage	24V

Figure 20: FSP302PV-230F-24

$$AC\ Power = 4.841\,kW$$

$$Minimum\ Nominal\ Power\ Rating = (4.841\,\mathrm{kW}/0.98) = 4.939\,\mathrm{kW}$$

Final

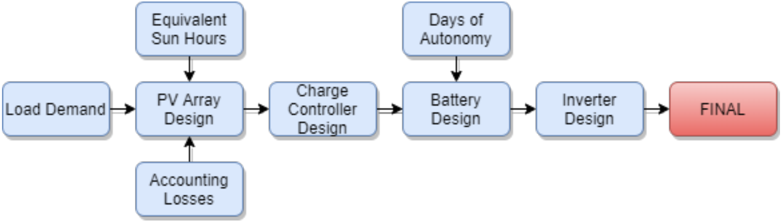


Figure 21: Step of Design Methodology

Climate Data
The MeteoSyn Climate database contains about 450 climate data provided by Deutsche Wetterdienst for Germany for 1981-2010 and more than 8,000 climate data available for 1986-2005 in the world and meteonorm 7.1 base. Climate data can be easily selected on the map.

Components Database
The broad base module and inverter database can contain 13 000 modules and 3 100 inverter records and the database automatically updates itself. Records to the database are updated by manufacturers. It can create favorite lists to achieve faster results.

These datas http://pvsol-online.valentin-software.com/ belong to the site.

Battery Storage

Select the battery to be used in your own battery storage system, and determine and design the inverter and charge controller.
With safe and approved simulation results, you can evaluate your self-consumption and independence rate.

Photo Plan

With the roof exploration / measurement software integrated into Photo Plan, the dimensions of the roof can be calculated easily and quickly. By visualizing a photovoltaic system to be installed on the roof with reference points and the required roof dimensions can be provided from the software.With the roof exploration / measurement software integrated into Photo Plan, the dimensions of the roof can be calculated easily and quickly. By visualizing a photovoltaic system to be installed on the roof with reference points and the required roof dimensions can be provided from the software.

These datas http://pvsol-online.valentin-software.com/ belong to the site.

Simulation Results

The result summary presents detailed simulation results, tables and cash flows. With the energy balance sheet, all income and losses of a photovoltaic system can be evaluated. All results and system details can be presented as desired.

Software Maintenance

Software maintenance involves updating both the software and databases. One year maintenance fee is included in the software fee from the date of purchase.

These datas http://pvsol-online.valentin-software.com/ belong to the site.

The meteorological data of the location marked on the map are loaded.

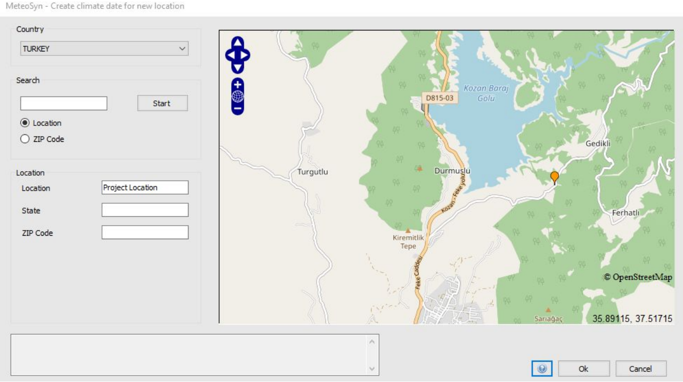


Figure 22: Climate Data Selection on PV*SOL

Individual appliance models:

- User-Independent Appliance
- User-Dependent Appliance
- Short-time Use Appliance
- Light

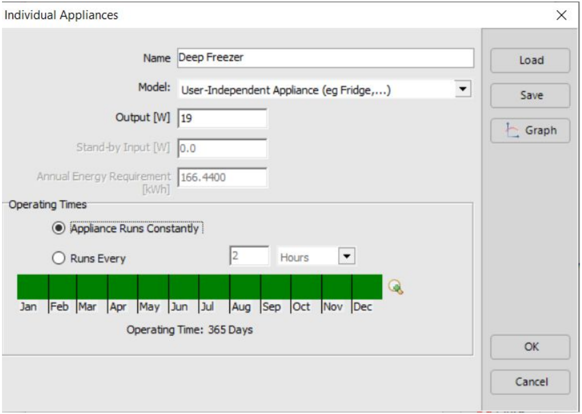


Figure 23: Example/User-Independent Appliance

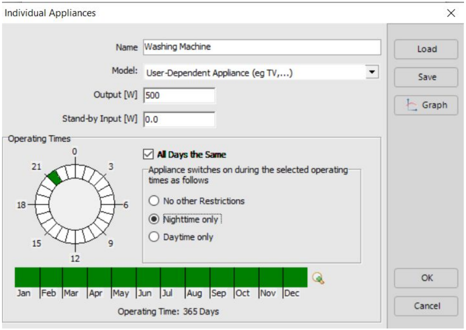


Figure 24: Example/User-Dependent Appliance

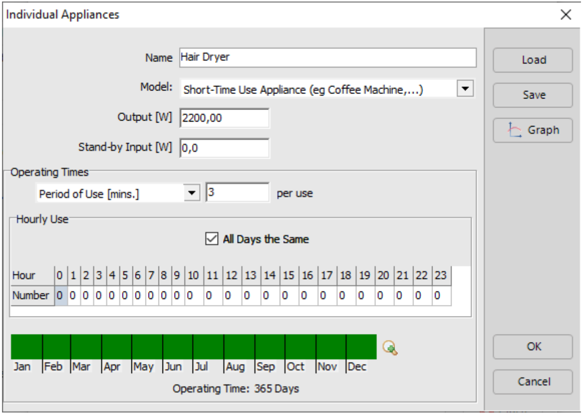


Figure 25: Example/Short-Time Use Appliance

The list does not consist this load.

Design on PV*SOL

Consumption

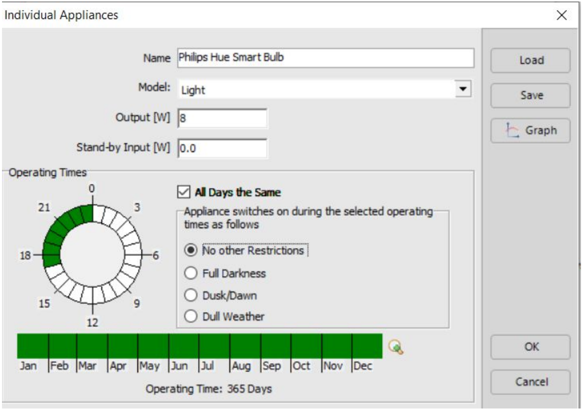


Figure 26: Example/Light

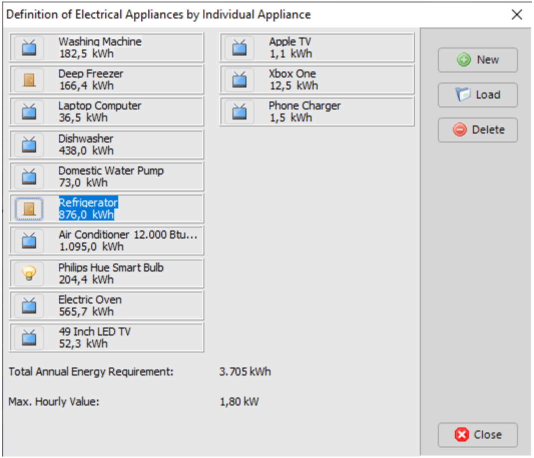


Figure 27: Consumtion/Appliances List

Design on PV*SOL

PV Array Design

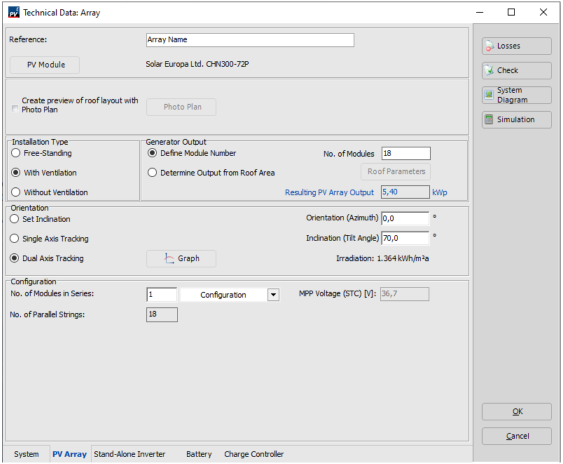


Figure 28: PV Array

Design on PV*SOL

Battery Design

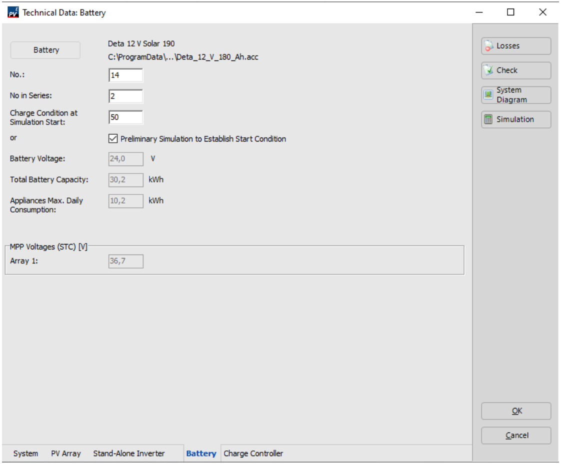


Figure 29: Battery

Design on PV*SOL

Charge Controller Design

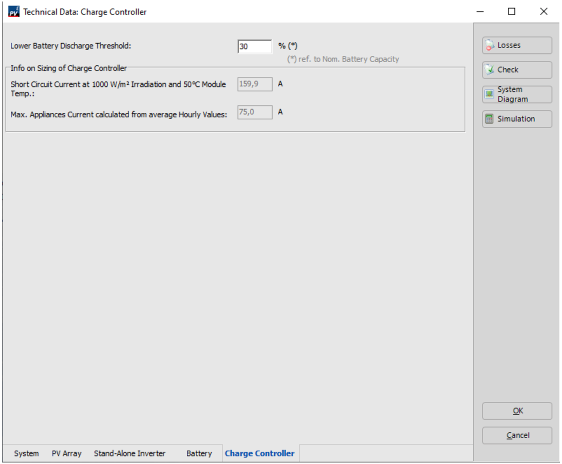


Figure 30: Charge Controller

Design on PV*SOL

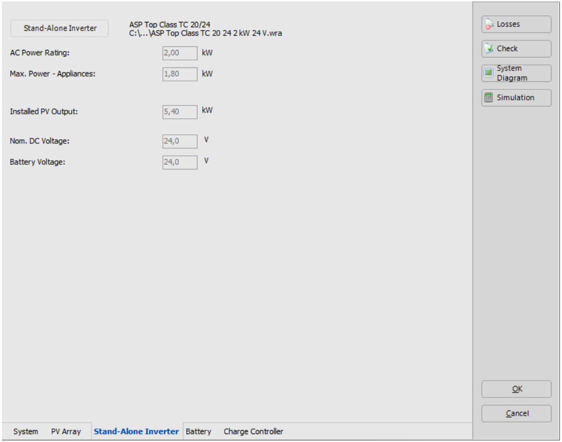


Figure 31: Stand-Alone Inverter

Design on PV*SOL

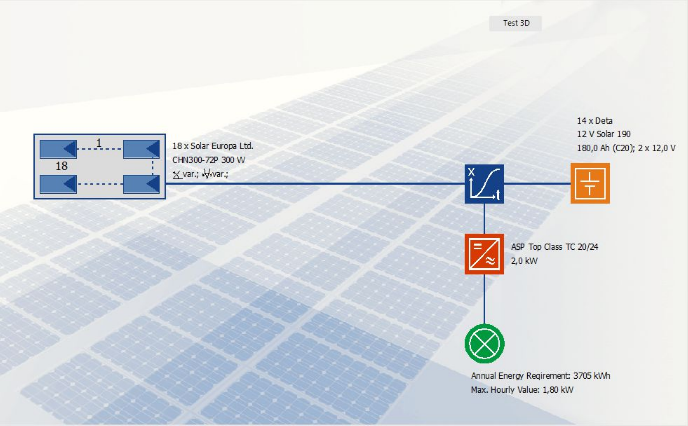


Figure 32: System

Design on PV*SOL

Report

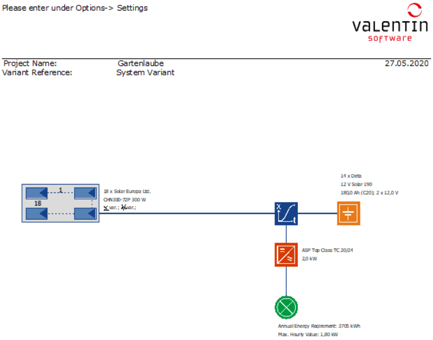


Figure 33: Report/Page 1

Location:	House_Kozan/Adana
Climate Data Record:	House_Kozan/Adana (1981-2000)
PV Output:	5,40 kWp
Gross/Active PV Surface Area:	34,75 / 34,60 m²

PV Array Irradiation:	47.178 kWh
Energy Produced by PV Array:	4.906,8 kWh
Consumption Requirement:	3.704,9 kWh
Consumption Covered by Solar Energy:	2.961,5 kWh
Consumption Not Covered by System:	743,5 kWh

Solar Fraction:	79,9 %
Performance Ratio:	40,2 %
Specific Annual Yield:	548,4 kWh/kWp
CO2 Emissions Avoided:	1.819 kg/a
System Efficiency:	6,3 %
PV Array Efficiency:	10,4 %

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

PV*SOL Expert 5.5 (R2) 1

Figure 34: Report/Page 2

Analysis

Problem:

Looking at the second part of the report, consumption not covered by system=743.5 kWh will be seen.

This cannot be tolerated because the system is off-grid.

Solution

Back up generator can be used to reset this value.

Design on PV*SOL

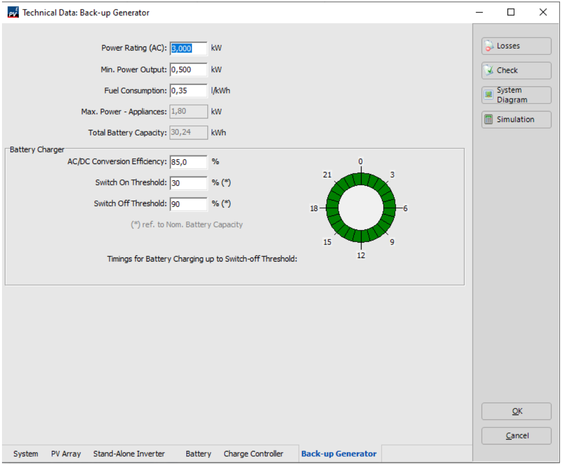


Figure 35: Back-up Generator

Design on PV*SOL

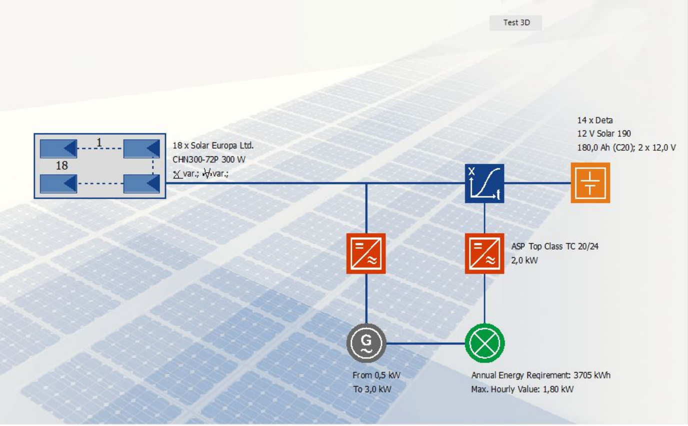


Figure 36: System

Design on PV*SOL

Report

Please enter under Options-> Settings

Project Name: Gartenlaube 27.05.2020
Variant Reference: System Variant

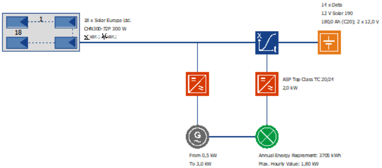


Figure 37: Report/Page 1

Location:	House_Kozan/Adana
Climate Data Record:	House_Kozan/Adana (1981-2000)
PV Output:	5,40 kWp
Gross/Active PV Surface Area:	34,75 / 34,60 m²

PV Array Irradiation:	47.178 kWh
Energy Produced by PV Array:	4.981,7 kWh
Energy Produced by Back-up Generator:	1.141,9 kWh
Consumption Requirement:	3.704,9 kWh
Consumption Covered by Solar Energy:	2.949,5 kWh
Consumption Covered by Back-up Generator:	755,46 kWh
Consumption Not Covered by System:	0,0 kWh

Solar Fraction:	79,6 %
Performance Ratio:	40,1 %
Specific Annual Yield:	546,2 kWh/kWp
CO2 Emissions Avoided:	2.675 kg/a
System Efficiency:	6,3 %
PV Array Efficiency:	10,6 %

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

PV*SOL Expert 5.5 (R2) 1

Figure 38: Report/Page 2

Design on PV*SOL

3d Visualization

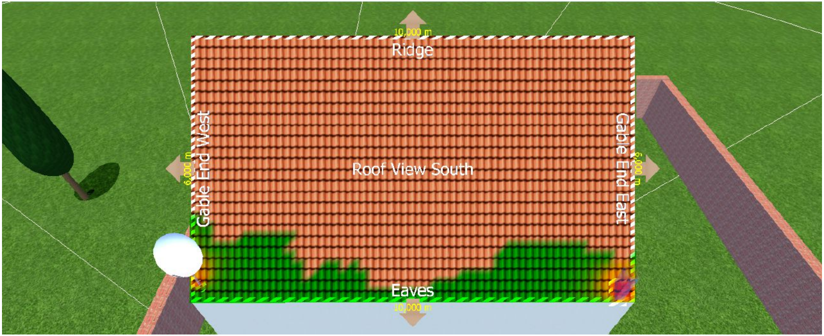


Figure 39: Shade Frequency Distribution

Design on PV*SOL

3d Visualization

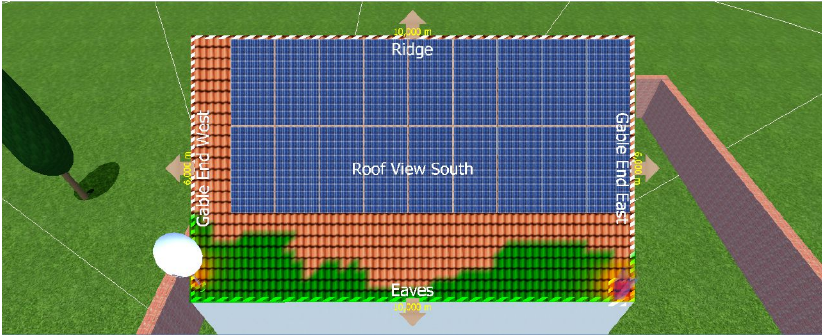


Figure 40: Shade Frequency Distribution with PV Panels

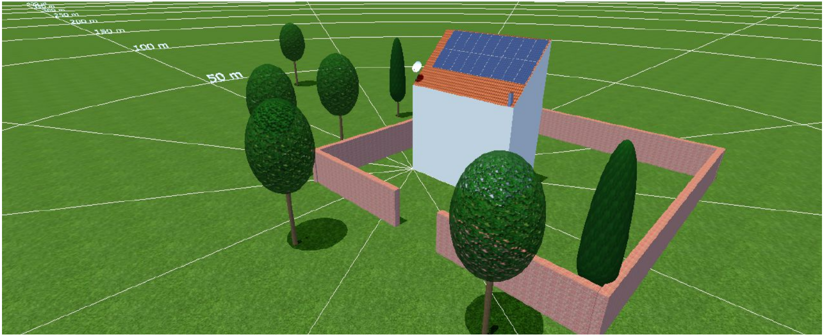


Figure 41: South East View

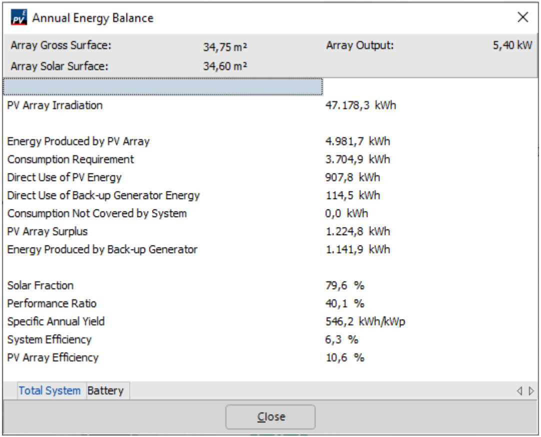


Figure 42: Annual Energy Balance/Total System

Design on PV*SOL

System Analysis

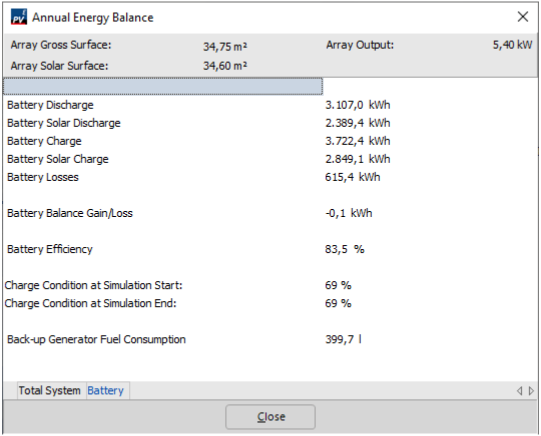


Figure 43: Annual Energy Balance/Battery

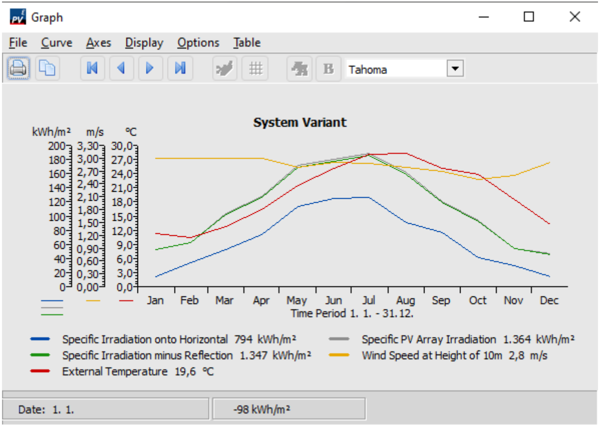


Figure 44: Climate Data Analysis

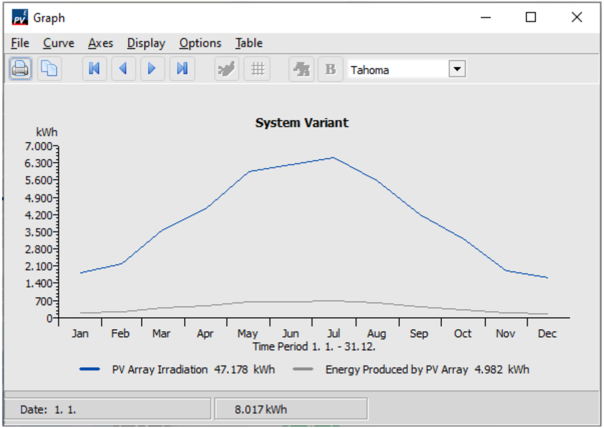


Figure 45: PV Array Irradiation-Energy Produced by PV Array Analysis

Figure 46: Consumption Analysis

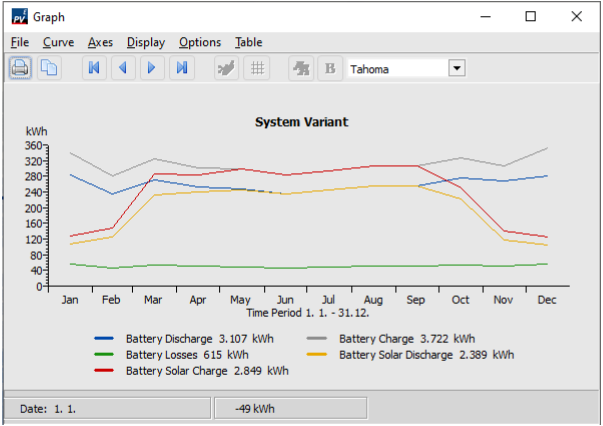


Figure 47: Battery Analysis

Design on PV*SOL

System Analysis

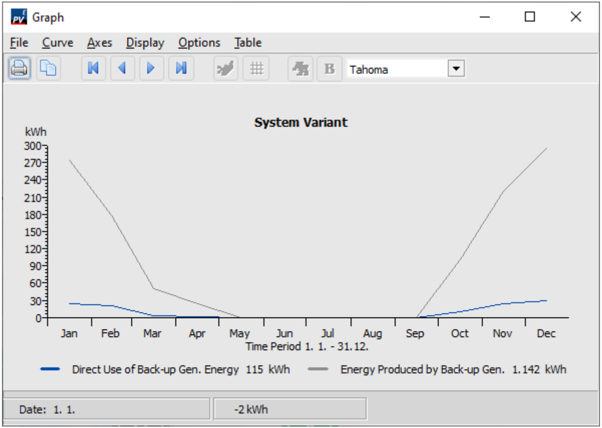


Figure 48: Back-up Generator Analysis

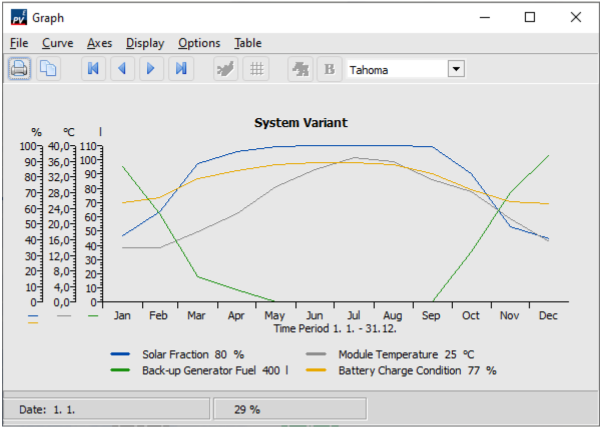


Figure 49: Total System Analysis

Turkish Banks Loan Support

List of Turkish Banks Loan Support

- Turkiye Is Bankasi
- Garanti BBVA
- Halkbank
- Turkiye Finans

Turkish Banks Loan Support

IS Bankasi

Installed power less than 5 MW&Electricity production based on solar, wind and other renewable energy sources

Features

- Unlicensed electricity production projects are exempted from the obligation to obtain a license from EMRA and to establish a company.
- For the surplus part produced, purchase guarantee is given by the relevant electricity network operator from the tariff determined for a period of 10 years. This enables investors to generate as much electricity as they need, and to generate income by selling surplus production to the network operator.
- Documents pertaining to all legal approvals / permits required for unlicensed energy projects, especially the agreements signed with the network operator prior to credit disbursement, and the policy showing that the facility is insured should be submitted to Bank.
- Disbursements made in foreign currencies are limited to USD and EUR.

[1]

Turkish Banks Loan Support

Garanti BBVA

Installed power less than 1 MW&Electricity production from solar energy.

Features

- Real or legal enterprises that have at least one consumption facility, that is, electricity subscription and who want to produce unlicensed electricity from solar energy 1MW and below can establish PV plant without license.
- Additional conditions, including the submission of the Connection Agreement signed with the electricity grid operator, must be met at the time of credit issuance.
- Credit can be used with a grace period up to 2 years and a payment plan suitable for cash flow.
- The loan can be used in TL or foreign currency.
- The excess electricity you produce is guaranteed to be purchased over the tariff determined for 10 years with the legal regulation.

[2]

Turkish Banks Loan Support

Halkbank

Installed power less than 1 MW&Electricity production from solar energy and wind energ.

Features

- Those who want to produce unlicensed electricity should be electricity subscribers real and legal persons.
- Necessary licenses and permits have been obtained to obtain credit and the project must be approved.
- Investment loan 2 years grace period 7 years term.
- Business loan 2 years grace period 7 years term.
- The loan can be used in TL or foreign currency.

[3]

Turkish Banks Loan Support

Turkiye Finans

Installed power less than 1 MW&Electricity production based on solar, wind and other renewable energy sources

Features

- Those who want to produce unlicensed electricity should be electricity subscribers real and legal persons.
- Low cost and advantageous profit rates with 10% discount on signage prices in TL and foreign currency loans for Corporate and Commercial customers
- As a result of the project-based evaluation, up to 1 year of non-refundable, up to 5 years in total, the opportunity to make appropriate term.
- Fixed cost advantage that protects your business against economic volatility.
- The loan can be used in TL or foreign currency.

[4]

- Project Scope
- Market Feasibility(N/A)
- Technical Feasibility
- Financial Feasibility
- Results

N/A(This section has been left blank since no energy was produced to be sold.)

An off-grid rooftop PV power plant for a duplex apartment in the following coordinates and features:

- 37.50404415 35.86275261
- Surface area belonging to the duplex apartment is 60 square meters (Rectangle: 6 m x 10 m)

The panel system, which gives efficient outputs as a result of simulation, will be installed on the roof.

Materials Needed:

- PV Panels
- Batteries
- Charge Controller
- Inverter
- Cables
- Measurement Equipments
- a Simulate Software(PV*SOL)
- Climate Data

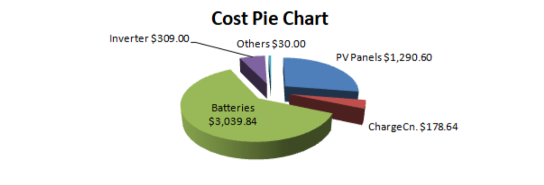
ELECTRIC BILL			
CONSUMPTION DATA			
Daytime Index (kWh	Puant Index (kWh)	Night Index (kWh)	Total (kWh)
51.6	158.4	95.7	305.70
BILL DETAILS			
Consumption (kWh)			305.7
Unit Price			₺ 0.574
Energy Consumption Price			₺ 175.48
Taxes&Funds			
Energy Fund+TRT+etc.			₺ 14.04
KDV %18 (Tax Assessment ECP+EF+TRT+etc)			₺ 34.11
--			
Bill Amount			₺ 223.63
//			
Unit price, taxes&funds etc. values belong to a sample invoice of Enerjisa Company.			
//			
Designed by Türker Aşkın Kabadayı on Microsoft Excel for EEE407 Project.			

Figure 50: Electric Bill

Feasibility Study

Financial Feasibility

COST REPORT					
Appliance	Manufacturer	Model	Quantity	Unit Price	Price
PV Panel	Chinaland Solar Energy	CHN300-72P	9	$ 143.40	$ 1,290.60
MPPT Charge Cont.	Epever	4215BN	1	$ 178.64	$ 178.64
Battery	DETA	12V Solar 190	16	$ 179.99	$ 2,879.84
Off-Grid Inverter	Essen Solar	FSP302PV-230F-24	1	$ 309.00	$ 309.00
Another (cables, installation equipment etc.)					$ 30.00
Total Price					$ 4,688.08
Total Price					₺ 32,744.36



Exchange Rate (1 USD = 6.9846 TL)

Designed by Türker Aşkın Kabadayı on Microsoft Excel for EEE407 Project.

Figure 51: Cost Report

With a simple calculation, how many years the system will payback for itself is found as follows:

$32{,}744.10\,\text{tl} \;/\; (223.63\,\text{tl} \times 12) = 12.2$

12 years

Feasibility Study

Financial Feasibility on PV*SOL

Please enter under Options-> Settings **PV*SOL Expert 5.5 (R2)**

Gartenlaube

Variant Reference: System Variant Date: 28.05.2020

-Economic Efficiency Calculation-

System	
PV Output:	5,400 kWp
Gross PV Surface Area:	34,75 m²
Back-up Generator:	3,00 kW

Electricity Balance	
Appliances - Requirement:	3.705 kWh
PV Array Generated Energy:	4.982 kWh
Back-up Generator Energy:	1.142 kWh

Fuel Costs	
Specific Fuel Costs:	1,50 ?/Liter

Figure 52: Economic Efficiency Calculation

Economic Efficiency Parameters	
Lifespan of Modules:	25 Years
Lifespan of Electronics:	25 Years
Lifespan of Battery:	5 Years
Lifespan of Back-up Generator:	25 Years
Price Increase Rate for Battery:	0 %
Interest on Capital:	4,7 %
Price Increase Rate for Service Costs:	2,0 %
Price Increase Rate for Fuel Costs:	3,0 %

Costs (Cash Value)	
PV System Investment:	-41.035 ?
PV Modules:	-16.800 ?
Electronics:	-5.600 ?
Battery:	-18.635 ?
Back-up Generator Investment:	-1.200 ?
PV System Subsidy:	0 ?
PV System Running Costs:	0 ?
Back-up Generator Running Costs:	0 ?

Figure 53: Economic Efficiency Calculation

Total Electricity Production Costs:	**0,61 ?/kWh**
PV Electricity Production Costs:	**0,57 ?/kWh**
Back-up Gen. Electricity Production Costs:	**0,79 ?/kWh**
Total Annual Costs:	**3.723 ?/a**
PV System Annual Costs:	**2.825 ?/a**
Back-up Generator Annual Costs:	**898 ?/a**

Economic Efficiency Calculation according to the net present value methods.
Other methods can lead to other results.

Figure 54: Economic Efficiency Calculation

When the system is install on the right foundations, it will definitely be successful and its financial return will be high.
So why solar energy?

- Saves Money on Invoices
- Increases the Value of Your Home
- Provides Long Term Warranty To Its User
- Waste Free And Environmentally Friendly
- Saves Energy from Dependence on Foreign

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Thank you
for your attention