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Economic aspects related to the installation of photovoltaic modules in a camping car

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Abstract

As it is well-known, during the last couple of years several efforts have been made in order to get cars more efficient and less oil dependent. One way to reach this target is to develop green energy solutions based on on-board energy storage, but also on on-board energy production.

In this paper, economic aspects of power generation using a photovoltaic system integrated on a camping car is described and discussed. For other hand, micro-generation systems using renewable energies can contribute significantly not only to reduce the pollutant emissions but also to improve the energy balances of the modern societies.

Using as reference a camping car with a plug-in hybrid configuration, this paper examines technical and economical aspects related with the installation of photovoltaic modules in a camping car. The used camping car electric drive is a parallel configuration, which allows charging the electric energy storage systems using the AC grid or the photovoltaic power generation system.

The economic analysis is performed using solar irradiation data of three regions of Portugal (Oporto, Lisbon and Faro) considering and discussing the policies and legal issues in terms of energy market, micro-generation systems and hybrid electric vehicles.

Keywords: photovoltaic, battery, V2G (vehicle to grid), HEV (hybrid electric vehicle), energy storage

1 Introduction

Nowadays, societies all over the world are facing some difficulties originated, mainly, by the increasing price of oil. This trend in the oil price, as well as, the regulatory items about the CO_2 emissions will drift certainly into a change of the actual energy paradigm. In developed societies, the increasing demand of energy is also due to the increasing number of road vehicles. As it is well known, most of the road vehicles are oil addicted.

At the present time, the models and number of Electric Vehicles (EVs) circulating all over the world and particularly in Portugal are not very significant when compared with the number of pure Internal Combustion Engine (ICE) vehicles. However, the number of EVs has been slowly increasing and a boom isexpected in the coming years.

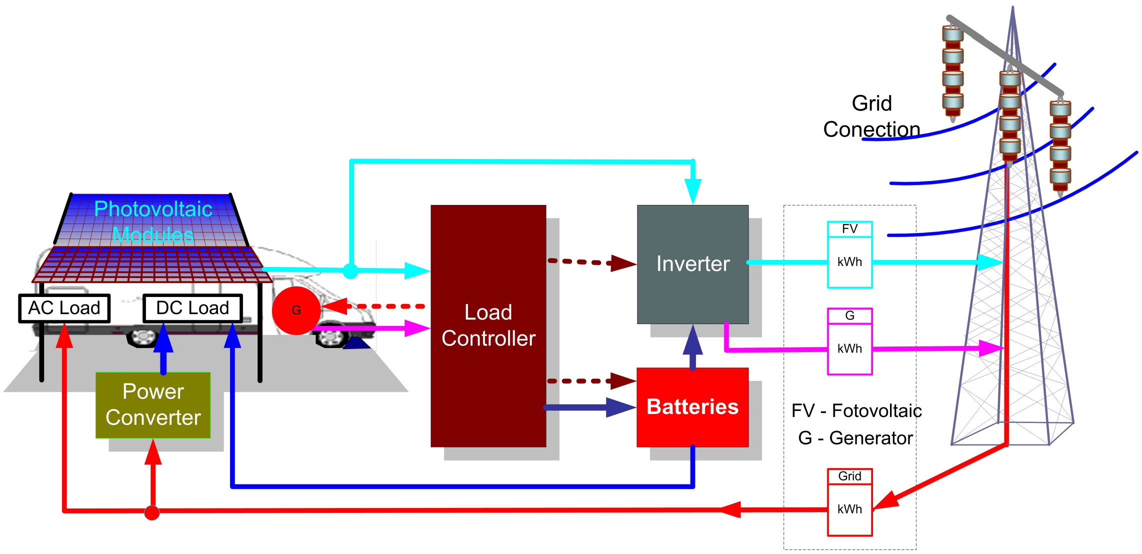


Figure1: Global diagram of the system

Under this scenario, increasing the number of EVs and fostering the introduction of Hybrid Electric Vehicles (HEVs) circulating (replacing the ICE vehicles) will contribute to a rise in the electric power consumption. In addition, new technological challenges will be launched, not only related to the charging points but also related to the impact of such systems in the electrical grids, as for instance vehicle-to-grid (V2G) technologies.

Using as reference a camping car with a plug-in hybrid configuration, this paper examines the technical and economical aspects related with the installation of photovoltaic modules in a camping car. The used camping car electric drive has a parallel configuration, which allows charging the electric energy storage systems using the AC grid or the photovoltaic power generation system as represented in figure 1.
Being the cars prepared to be charged from the AC grid, it is also possible to charge the storage systems using isolated electric power generation systems. Among the known possibilities, it is doable to assemble cars with photovoltaic modules, in particular, cars that are specially assembled, as for instance, placing photovoltaic modules in the area over the car roof. When camping, additional photovoltaic modules can be used and installed in external areas improving the power production capacity.

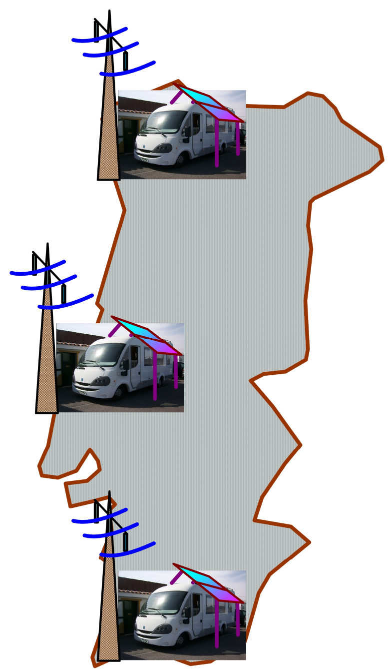


Figure2: Three different regions of Portugal considered in the performed economical analysis

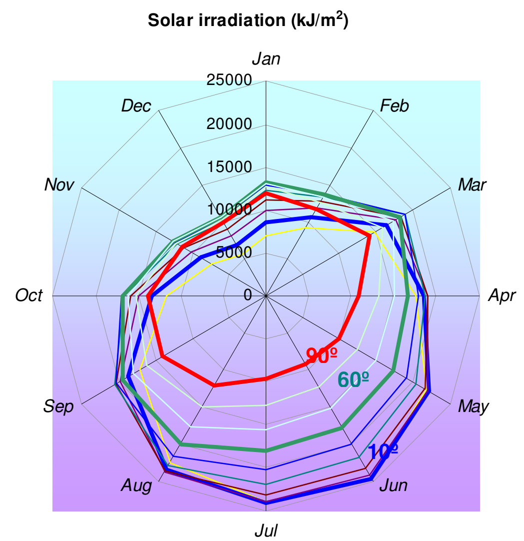
In this paper, a integrated solution based on a camping car with photovoltaic modules over the roof and on-ground is presented. The main aspects of the system are described above. Conclusions and comments are pointed out taking into consideration the power balance of a camping car when parked in three different regions of Portugal, as shown in figure 2.

2 Characterization of the solar irradiation

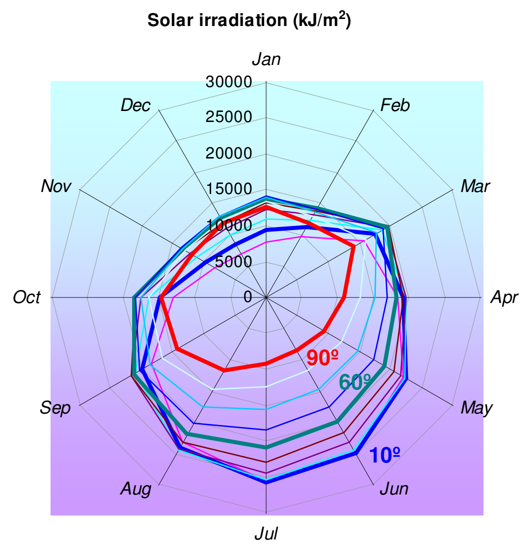
In order to analyse the economical aspects of the proposed system, the solar radiation data obtained for three distinct Portuguese places were used considering different slopes (0º to 90º), as represented in figure 3.

As it can be observed in figure 3:

- in the Oporto region, the maximum solar irradiation occurs in June with a slope of 10º;
- in Lisbon and Faro, the maximum solar irradiation occurs in July with a slope of 10º.

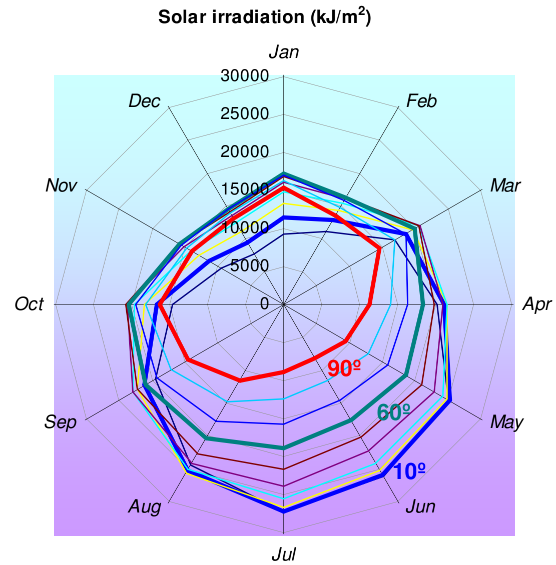


a) Oporto



b) Lisbon

Figure 3: Solar irradiation for the three different regions of Portugal considering different slopes



c) Faro

Figure 3: Solar irradiation for the three different regions of Portugal considering different slopes (cont.)

Anyway, due to the technical aspects related with the slope adjustment of the photovoltaic modules, for the regions studied, it can be concluded that the following inclinations can optimize the energy production:

- 10º from April to September; and
- 60º from October to March.

3 Characterization of the system

In general, inside of a camping car it is possible to find domestic electrical devices similar to that we have in conventional houses. Furthermore, some are DC supplied and other AC supplied. Anyway, in general, this type of cars owns electrical circuits prepared to supply DC or AC loads. Furthermore, some electric equipment is already prepared to be supplied by AC or DC power supplies. Anyway, the efficiency of each apparatus can be different when supplied from AC or DC supplies.

Taking into account the daily life needs and usage of domestic electric devices a list of electrical equipment used on-board of a camping is detailed in table 1.

According to the estimated power consumption shown in table 1, the energy consumption of the camping car (using the applicable Portuguese electric tariff) is 16 €/month. In order to simplify the economical analysis, it was considered this average consumption constant along the year.

Table 1: Camping Car Power Demand

Devices	Quantity	Power (W)	Nb. of hours	Power Consum. (Wh)
DC Power demand per day				
Int. lights	5	11	2	110
Ext. lights	1	20	2	40
Refrigerat.	1	60	12	720
Total DC Consumption (Wh)				870
AC Power Demand per day				
TV set	1	50	4	200
Wash mac.	1	500	0,75	375
Dishmach.	1	500	1	500
Computer	1	150	2	300
Air Cond.	1	500	3	1500
Air Fan	1	50	1	50
Other equipment	4	100	0.25	100
Inverter	1			455
Total AC Consumption (Wh)				3480
DC + AC Consumption (Wh)				**4350**

3.1 Power generated

Taking into account the free area available over the car roof and the surrounding car area, two sets of photovoltaic modules can be integrated on the camping car. Considering the possibility of use these two sets of PV modules together or separately (table 2), the main characteristics of each set are presented.

Table 2: Main characteristics of the two set of photovoltaic modules

	Panel #1	Panel #2
Width (m)	1,6	1,2
Size (m)	4,8	3,4
Area (m^2)	7,7	4,1
Number of PV modules	8	6
	PV modules	
Power peak (Wp)	175	
Size (m)	1,58	
Width (m)	0,808	
Thickness (m)	0,035	
Area (m^2)	1,277	
Power density (Wp/m^2)	137,1	

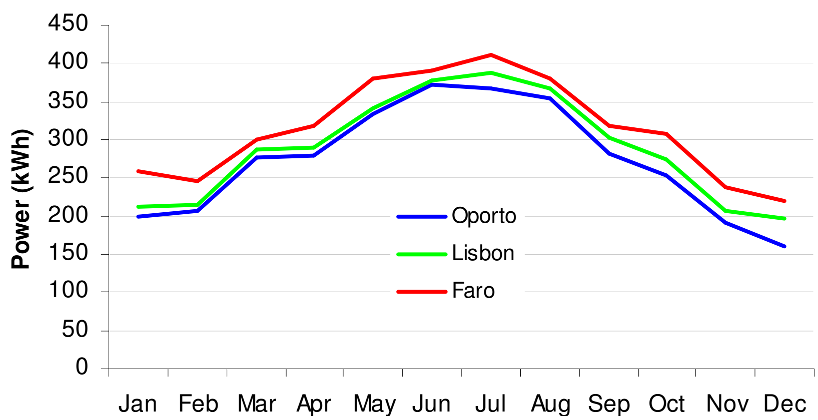


Figure3: Power generated by the photovoltaic system

In figure 3, the annual evolution for the power generated using the two sets of PV modules, in the three Portuguese regions is represented. As it can be observed, the power production is maximized in the months of June, July and August. As it was expected according to the solar irradiation data, Faro is the best region to use photovoltaic systems producing electric energy.

3.2 Costs of the PV system

Economic aspects of such systems evolve several factors. The analysis performed was launched based on the estimation of the camping car power demand (Table 1) and on the costs of a PV system designed to fulfill these technical requirements (Table 3).

Table 3: Costs of the PV system

Equipment	Quantity	Cost (€/un.)	Cost (€)
Photovoltaic module (175Wp)	14	1000	14000
Batteries	6	460	2760
Load controller (30 A)	1	134	134
Electric motor (all system)	1	6000	6000
Inverter (2 kW)	1	1800	1800
Electric SystemTotal Cost			24694
Instalation cost			2469,4
Total			27163,4

3.3 Incomes

Being the system based on a hybrid camping car, the system owns two types of incomes:

- one is related with the electric traction chain that is more economical attractive than the pure internal combustion engines. It is estimated that the electric chain can contribute to up to 50% the oil consumption of a car, which corresponds to 500 € of saves if the car runs 20000 km/year.

- the other income is directly related to the electric energy generated by the PV system and sold.

The considered feed-in tariff for the produced electric energy in Portugal applicable to the PV system under study is 0,65 €/kWh in the first 5 years contract.

Under this scenario, for each of the considered regions, the incomes due to the PV energy sold during one year, are the following:

- Oporto: 1945 €;
- Lisbon: 2068 €;
- Faro: 2262 €.

4 Economical Analysis

About the models used to perform the economic analysis, different scenarios can be tested taking into account the following factors and situations: car camping parked in three distinct regions in terms of solar irradiation; slope of the PV modules; life time of the project; and, interest rate.

Considering that the life time of the PV system is 20 years and considering the slopes referred in the point 2 of this paper and, taking into account all the values referred in the previous points of this paper, tables 4, 5 and 6 summarize the main results of the economical analysis of the described system for the three considered regions.

Table 4: Economic Analysis (20 Years) – Oporto – 14 PV Modules

Year	0	1	2	3	4	5	6	7	8	9	10
Power saves (Fuel+Electric energy sold		2445,0	2616,3	2799,4	2995,4	3205,1	3429,4	3669,5	3926,4	4201,2	4495,3
O&M (year rate: 1%)		-272,0	-285,2	-299,5	-314,5	-330,2	-346,7	-364,0	-382,2	-401,3	-421,4
Investment	-27163,4										
Cash-flow	-27163,4	2174	2331,1	2500,0	2681,0	2874,9	3082,8	3305,5	3544,1	3799,9	4073,9
Pay-back	-27163,4	-24990	-22658,8	-20158,8	-17477,9	-14603,0	-11520,2	-8214,7	-4670,6	-870,7	3203,2
IRR (20 years)						-20,50%	-13,18%	-7,80%	-3,73%	-0,59%	1,88%

Year		11	12	13	14	15	16	17	18	19	20
Power saves (Fuel+Electric energy sold)		4810,0	5146,7	5506,9	5892,4	6304,9	6746,2	7218,5	7723,8	8264,4	8842,9
O&M (year rate: 1%)		-442,5	-464,6	-487,8	-512,2	-537,8	-564,7	-592,9	-622,6	-653,7	-686,4
Investment											
Cash-flow		4367,5	4682,1	5019,1	5380,2	5767,1	6181,5	6625,5	7101,2	7610,7	8156,5
Pay-back		7570,7	12252,8	17271,9	22652,1	28419,2	34600,7	41226,2	48327,4	55938,1	64094,6
IRR (20 years)		3,85%	5,45%	6,77%	7,86%	8,78%	9,55%	10,21%	10,77%	11,26%	11,68%

Table 5: Economic Analysis (20 Years) – Lisbon – 14 PV Modules

Year	0	1	2	3	4	5	6	7	8	9	10
Power saves (Fuel+Electric energy sold		2568	2747,3	2939,6	3145,4	3365,5	3601,1	3853,2	4122,9	4411,5	4720,3
O&M (year rate: 1%)		-272	-285,2	-299,5	-314,5	-330,2	-346,7	-364,0	-382,2	-401,3	-421,4
Investment	-27163,4										
Cash-flow	-27163,4	2296	2462,1	2640,1	2830,9	3035,4	3254,4	3489,2	3740,7	4010,2	4298,9
Pay-back	-27163,4	-24867	-22405,4	-19765,3	-16934,4	-13899,0	-10644,6	-7155,4	-3414,7	595,5	4894,5
IRR (20 years)						-19,28%	-12,02%	-6,69%	-2,69%	0,40%	2,82%

Year		11	12	13	14	15	16	17	18	19	20
Power saves (Fuel+Electric energy sold)		5050,8	5404,3	5782,6	6187,4	6620,5	7084,0	7579,8	8110,4	8678,2	9285,6
O&M (year rate: 1%)		-442,5	-464,6	-487,8	-512,2	-537,8	-564,7	-592,9	-622,6	-653,7	-686,4
Investment											
Cash-flow		4608,3	4939,7	5294,8	5675,2	6082,7	6519,2	6986,9	7487,8	8024,4	8599,2
Pay-back		9502,8	14442,5	19737,3	25412,5	31495,2	38014,4	45001,3	52489,2	60513,6	69112,8
IRR (20 years)		4,75%	6,32%	7,60%	8,66%	9,55%	10,30%	10,93%	11,48%	11,94%	12,35%

Table 6: Economic Analysis (20 Years) – Faro – 14 PV Modules

Year	0	1	2	3	4	5	6	7	8	9	10
Power saves (Fuel+Electric energy sold		2762	2955,1	3161,9	3383,3	3620,1	3873,5	4144,6	4434,8	4745,2	5077,4
O&M (year rate: 1%)		-272	-285,2	-299,5	-314,5	-330,2	-346,7	-364,0	-382,2	-401,3	-421,4
Investment	-27163,4										
Cash-flow	-27163,4	2490	2669,9	2862,5	3068,8	3289,9	3526,8	3780,6	4052,6	4343,9	4656,0
Pay-back	-27163,4	-24673	-22003,4	-19141,0	-16072,2	-12782,2	-9255,4	-5474,8	-1422,2	2921,6	7577,6
IRR (20 years)					-27,53%	-17,41%	-10,24%	-5,01%	-1,09%	1,91%	4,26%

Year		11	12	13	14	15	16	17	18	19	20
Power saves (Fuel+Electric energy sold)		5432,8	5813,1	6220,0	6655,4	7121,3	7619,8	8153,1	8723,9	9334,5	9987,9
O&M (year rate: 1%)		-442,5	-464,6	-487,8	-512,2	-537,8	-564,7	-592,9	-622,6	-653,7	-686,4
Investment											
Cash-flow		4990,3	5348,5	5732,2	6143,2	6583,5	7055,1	7560,2	8101,3	8680,8	9301,5
Pay-back		12567,9	17916,4	23648,6	29791,8	36375,2	43430,3	50990,5	59091,8	67772,6	77074,1
IRR (20 years)		6,13%	7,63%	8,86%	9,88%	10,72%	11,44%	12,04%	12,55%	12,99%	13,37%

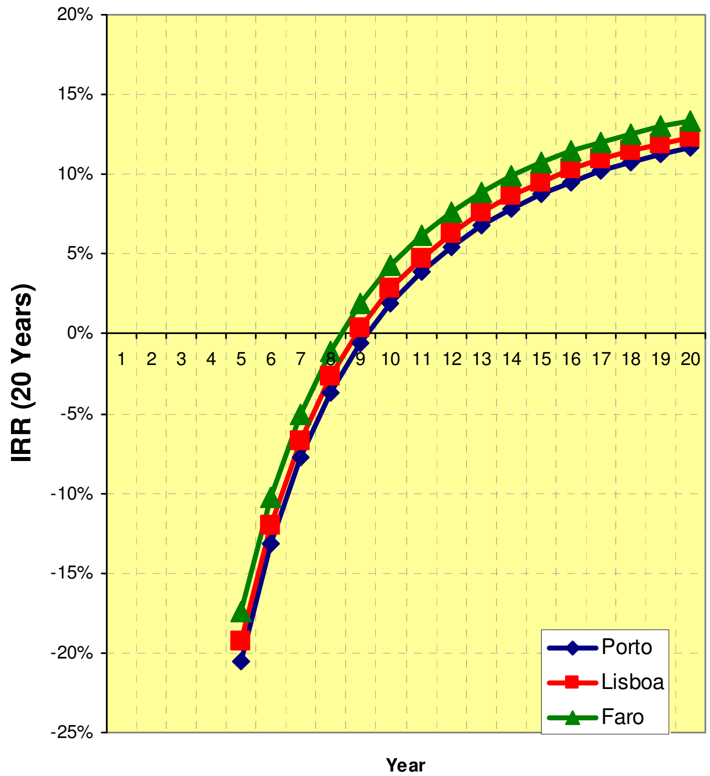


Figure4: Internal return rate for the project in the three regions

4.1 Technical factors

The technical factors can be discussed from different point of views and distinct perspectives.

About the system under study it is important to point out that:

- The camping car has an hybrid configuration;
- The photovoltaic system power production is not enough to assure the autonomy required by car owners;
- To take advantage of the electric chains on-board and to improve the system capabilities, the car should be a plug-in car.

Furthermore, the economical analysis is influenced by the following aspects:

- Car parked or running on the road;
- Solar irradiation and PV modules orientation;
- Effective efficiency of the photovoltaic modules;
- Management rules for the energy stored on-board;
- Price of the energy (oil price and kWh feed in tariff);
- Efficiency and performance of the electric chains;
- Batteries characteristics (capacity, size, power density, etc).

Anyway, taking into account the premises of the performed analysis, it clearly points out that this type of systems can contribute to save energy and therefore to reduce the operation costs.

4.2 Economic factors and analysis

About the models used to perform the economic analysis, different scenarios were tested taking into account, in addition to the factors previously referred, the following factors and situations: inclination of the PV modules; different power demand scenarios and, interest rate.

About the power demand scenarios, instead of taking into consideration average annual values, monthly values (taking into account the seasons) were also used. Anyway, globally, the economic results obtained were similar.

Considering that the life time of the PV system is 20 years, the pay-back is reached in less than 10 years for all the regions analysed, as it can be observed in figure 4. Anyway, this analysis can be considered optimistic knowing those 10 years are the life time of a camping car. At this point, in order to encourage the development, usage and attractiveness of such systems it is necessary to include in the discussion the transport policies, mainly the financial incentives that are necessary to spread this type of technical solution.

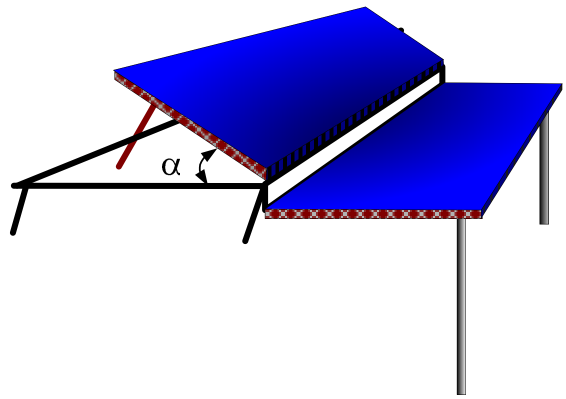
4.3 General remarks

First of all, considering the actual Portuguese feed-in tariff for micro generation the proposed solution is economically attractive. In addition, it can contribute do decrease the oil dependency taking advantage of the solar renewable energy.

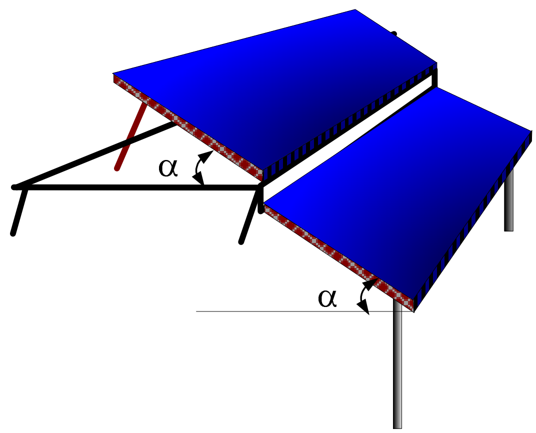
Being the system based on a hybrid camping car, in other investigations performed by the authors [18] it was considered that the car runs 20000 km/year being 10000 assured by the ICE and the other 10000 by the electric traction system. It was also assumed that the car has on-board batteries with adequate capacity and able to fulfil the car power demand. It is important to point out that the PV system can have 2 configurations (figure 5): over the car roof are placed 8 PV modules, which are always connected to the car electric system and, when parked, more 6 PV modules placed in the backyard of the car can be connected to the car electric system.

The running of the system, mainly the usage of 8 PV modules or 14 PV modules can be optimized increasing the power generated. Furthermore, the car trips should be arranged in order to improve the system efficiency.

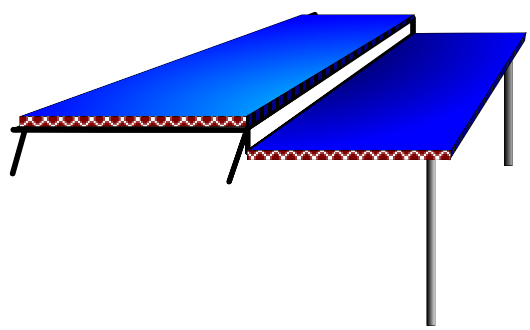
About the results shown in [18] and in order to complement this discussion, it is important to point out that under a scenario where the fuel price will increase 12%/year and the electric energy tariffs 4%/year, the owners of cars having the proposed PV system installed can save up to 9900 € in 20 years.



a) Configuration #1



b) Configuration #2



c) Configuration #3

Figure5: Three possible configurations for the two set of photovoltaic modules integrated in the camping car

5. Conclusions

In this work, economical aspects of a camping car with a plug-in hybrid configuration were analyzed in order to contribute to the discussion of the following issues: economic impact of the connection of the EVs into the low voltage AC grid; technical solutions allowing charging the EV using the domestic AC grid; technical solutions allowing to recover the energy stored on-board; interconnection with alternative energy solutions, mainly the domestic photovoltaic systems.

The performed analyses clearly underline the strong and weak aspects of the proposed configurations, not only from the technological point of view, but also, from the economical point of view.

Acknowledgments

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