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Feasibility of Recharging Electric Vehicles With Photovoltaic Solar Panels

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Abstract

There are many reasons for the development and the use of renewable energy sources, such as the public awareness in the fight against climate change, energy independence with the security of supply, national competitiveness, technological development and job creation in a sector that has a great future. In this line, and within the proposed electric vehicle sustainability, it is an alternative to achieve a reduction of pollutant emissions and to increase the efficiency of road transport.

The article presents a study of the use of electric vehicles from different points of view. It has been compared combustion vehicles with the electric counterparts in terms of power and features appreciated by the user in the automobile market.

The purpose of the study was to analyze the feasibility to recharge different electric vehicles by solar photovoltaic modules, so that energy generation would not contribute to any CO_2 emissions, when the system would be installed and ready to supply these vehicles. The study also shows a comparative analysis of the cost of purchasing electricity to the distributor compared with the using of a photovoltaic system designed to recharge the vehicle, even it has also been calculated the depreciation.

Finally, it has been analyzed comparatively the type of the solar photovoltaic system considered more economically viable for recharging a pure electric vehicle (EV) therefore it has been compared projects on houses and on a parking to recharge several vehicles.

Key words: Electric vehicle (EV); Solar photovoltaic system; Economically viable; Recharging

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1. INTRODUCTION

Renewable energy at this moment has to decide the development in the future. Despite the effects of the economic crisis, globally renewable energy continues significantly growing. More and more countries are implementing development plans for the implementation of this type of energy. There are many reasons for their development, it could be highlight:

- The fight against climate change: The electrification of the vehicle is an alternative for reducing emissions and to increase transport efficiency.
- Energy independence and security of supply.
- National competitiveness.
- Technological development.
- Job creation.

The high oil prices only reinforce this trend. It is hoped that renewable energy sources constitute one of the most important and greater growth and with more potential in the coming years. But nowadays renewable energy has to face with many alternatives like fossil fuels (coal, gas, oil) and nuclear power that also have to compete with each other.

In this situation, renewable project developers, governments and regulators should define a coherent strategy for the future and be careful in selecting their technology mix.

In addition to the generation, the transport produces also emissions of CO_2.

Transportation is the most energy-consumer in Spain, reaching to 39% of the national total. It should be noted that the tourism vehicle represents approximately the 15% of all energy consumed in Spain. Therefore renewable energy and its efficiency in transportation should be analyzed to obtain a sustainable mobility.

A photovoltaic system (PV) with photovoltaic solar panels to charge your electric vehicle (EV) or pure electric vehicle (PEV) will reduce the pollutions produced by fossil fuel and nuclear-made electricity—common grid sources.

The type and size of PV system that can provide charging for a PEV or EV varies widely. Typically, a PV system for PEV charging is much smaller than one designed to serve an EV's needs. You'll need to consider battery capacity and your daily commute, among other things, to arrive at a system to meet your PEV or EV needs.

EV owners might think about putting in PV array to directly charge the EV batteries, since PV-direct applications can be the most efficient and least costly of all system types.

1.1 Photovoltaic Current State Sector

Spain was in 2010 the second country in the world[1] in the installed capacity, after Germany. However, in that year the government approved The Royal Decree 14/2010, called by some people the "anti-photovoltaic" low, with plenty of changes that produced a period of stagnation. On the other hand, and more recently, on December 8 2011, it was published in the Official Gazette nº 1699/2011, the "regulating subsistence decree". However, all these new regulations only control the conditions of application, connection procedures and technical conditions for production facilities of low power electricity.

The most positive aspects of this new decree are that: it legalizes consumption facilities and it allows installing counters in parallel to compute the energy self-consumed and the generated energy yield to others, but it does not specify how it should be done.

Despite, "Net Balance legislation" is not regulated yet. "Net Balance" means that netting system power will allow to the consumer to self -produce some of their consumption, using the electrical system to "store" the surplus production pick injecting it into the network that could be later retrieval. This system has led to an increase of installed capacity in other countries like Germany.

The RD 1699/2011 allows these facilities to electricity consumers with a contracted power that not exceeding 100 kW. This is the type of system selected for analysis. The installation of a car park at a university has been taken as an example for "auto-consumption".

1.2 Current Status of the Electric Vehicle

Electric vehicles nowadays can be found in the market are: hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), battery electric vehicle (BEV or EV) or extended range electric (EREV). An operating scheme of each vehicle has been shown in Figure 1 and 2.

[1] Instituto para la diversificación y el ahorro de la Energía. www.idae.es

In this study we focus on the third case, the battery electric vehicle or also called "pure electric". These vehicles are powered only by an electric motor. The power supply comes from electricity stored in a battery that has to be charged via the electric network.

Pollutant emissions are null and great cost savings can be obtained by recharging with electricity instead of fuel.

Another major advantage of these vehicles is their efficiency, nearly 77% if energy is from renewable sources, and 25% for the combustion vehicle.

By contrast, the autonomy given by a battery is much lower than in a conventional vehicle and the current network is very limited for charging. This makes the user feel uncertainty.

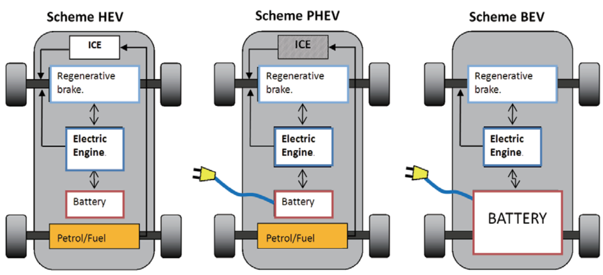

Figure 1
Types of Electric Vehicles: Hybrid (HEV)**, Plug-in Hybrid** (PHEV) **and Battery Electric** (BEV or EV)

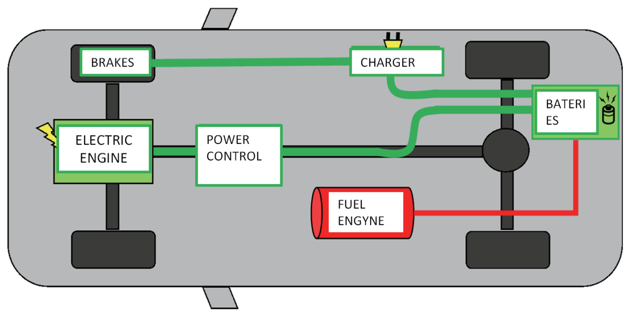

Figure 2
Scheme Extended-Range Electric Vehicle (EREV)

For charging infrastructure currently there are various possibilities on the market such as recharging posts for private car parks or for public use (single or multiple), wall points, etc. It is available with different options, such as personal identification via card prepaid systems management and monitoring software, smart charging with electrical protection and anti-theft security, etc..

The recharge rates depend on the electrical power supplied. So it can be recharged slowly (6 ~ 8 hours to recharge a battery of 24 kWh), semi-rapidly (3 ~ 4 h) and fast (15 ~ 30 minutes).

The future Technical Instruction REBT-52 (currently in draft) regulate electrical installations dedicated to electric vehicle charging[2]. On the other hand, the UNE -EN 61851

[2] http://www.f2i2.net/documentos/JVE_Jun2011/09_MITYC_

(conductive charging system for electric vehicles), defines the types and load modeling requirements to be used by electric vehicles in Spain:

• Mode 1. It Loads in a socket base, with "non-exclusive" use. (ac-ac. Up to 16 A per phase and a power of 3.7 to 11kW).

• Mode 2. Base standard outlet with protective non-exclusive use in the cable included. (AC with a 32 A current and a power of between 7.4 and 22 kW).

• Mode 3. Special socket used only for electric vehicle charging. (ca with a 64 A and a power of between 14.8 and 43 kW).

• Mode 4. DC connection. (cc-current, with a current of 400 A and a power of 50 to 150 kW).

Another important issue is the charging connectors, because currently there is a diversification, and standardization is needed. For this purpose, the European Committee for Electro-technical Standardization (CENELEC) issued a report in October 2011 with recommendations for the standardization of electric vehicle charging[5]:

• For modes 1 and 2: domestic outlets (Schuko) and industrial plugs (EN 60309-2).

• Mode 3: There are two possibilities:

or Type 2 (Mennekes)

or Type 3-c (Scame-Schneider-Legrand)

• Mode 4 (DC recharge) connector should find a "combo" that would be compatible with Type 1 (J1772) and type 2 (Mennekes). Also could work with mode 3 charging. The CHAdeMO standard (CHAdeMO Association - http://www.chademo.com/) could also be used, see Figure 3. Proposal "combo"[3]:

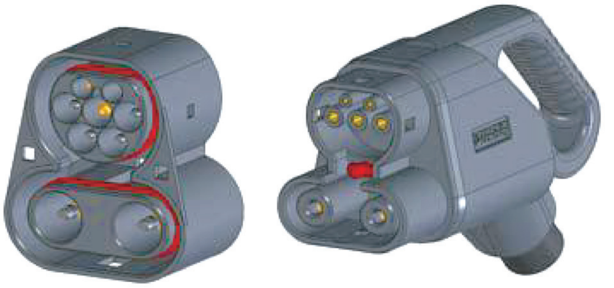

Figure 3
Example of Standard Vehicle Chademo Connector

The most critical component and incident in the price of electric vehicles is the battery. For these vehicles it has been taken a battery Li-Ion type due to their high specific energies, nominal voltages, and the low memory effect. Conversely, at extreme temperature it works worsen and its cost is still high. However, at medium or long term it is expected a decrease of their price, facilitating the acquisition of these vehicles.

2. CASE TO STUDY

The first objective of the research was to determine energy independence using electric vehicles recharged with solar photovoltaic supply.

The aim is to analyze if enough energy can be produced using these solar photovoltaic modules for recharging electric vehicles. It has been considered electric vehicles on the market today and its range of use. The most appropriate one has been selected regarding the distance traveled each day.

The second objective was to develop a model project module installation in a house and in a parking vehicle charging:

• Case 1: An individual who wants to recharge his electric vehicle in his home (house or villa). The photovoltaic system will be performed on the roof of the house.

• Case 2: A photovoltaic parking for 13 vehicles. The parking available at a university will be used as an example. An installation of photovoltaic modules above a canopy surface has been analyzed. Figure 4 shows an example of a small car park suitable for recharging electric vehicles with solar photovoltaic modules.

Figure 4
"Photolinere" at the University of Alcala in Madrid[4]

For sizing each of the facilities it will be taken into account factors such as the distance traveled by the vehicle, the number of vehicles to be connected, or the power consumption of these.

Third, the economic viability will be analyzed.

The acquisition of an electric vehicle with its combustion equivalent will be compared from two points of view: Firstly acquiring the energy to recharge the electric vehicle, and secondly using the PV system and producing our own energy.

infraestructura_para_la_recarga_del_VE.pdf

3 Report CEN-CENELEC: Standardization for road vehicles and associated infrastructure. Available at http://www.cencenelec.eu/standards/HotTopics/ElectricVehicles/Pages/default.aspx

4 http://www.motorpasionfuturo.com/coches-electricos/inaugura-la-primera-fotolinera- de-espana-enalcala-de-henares

The routes studied are 25, 50 and 100 km per day, with 5 different VE models, which give a total of 30 cases analyzed. Finally, we have performed an analysis of pollutant emissions that would be saved by using electric vehicles, whether the electricity comes from renewable energy (100 % of emissions avoided), as if it comes from non-renewable energy.

3. TECHNICAL AND ECONOMIC RESULTS

3.1 Development Project Type

a. Assumption 1: Houses

For the research it has been taken a Nissan Leaf vehicle[5]. It is a family tourism with an approximate consumption of 173 Wh/km, and a motorcycle "Vectrix VX -1 Li" with an approximate consumption of 50Wh/km. The distance of 50 km daily is driven by both, the total consumption of both vehicles would be 4070 kWh per year. If the system were "out of consumption" with "Net Balance" it would be needed about 10 photovoltaic modules (for example: the SLK Siliken P6L model[6]) of 240W, the production of the area would be 1590 kWh/kWp (per example in Alicante), it would be needed a system of 2,4 kWp . The "investor" to install could be the model: "SMA SB 2100 TL"[7]. The modules would be placed in two sets of five each one with an orientation of: 0° and tilt: 25 °. Finally the estimated budget of this facility would be approximately € 5,683.

b. Assumption 2: Parking

For this analysis has been considered a spectrum composed of different vehicles:

- Two Nissan Leaf ,
- 3 motorcycles Vectrix VX -1 Li,
- 3 Kangoo ZE (van),
- 2 Citroen C -Zero (urban tourism),
- and 3 Vectrix VX -2 (moped).

For a distance of 50 km per day if would be consumed 23479 kWh annually.

The facility would be with "auto-consumption" but not with "Net Balance", because the legislation does not allow it to consumers of more than 100 kW of power contracted, this is the case for a University or other organism with similar size.

For this case, it would be needed approximately 75 PV modules (for example the model "Siliken P6L SLK"[8]) of 240W, in the zone of Elche, for example, it wold be produced 1450 kWh/kWp. It would be needed a installation of 18 kWp.

The "investor" to install could be the "SMA STP 17000 TL -10"[9].

The modules would be placed in three series of twenty and one set of 15 with an orientation to the south of -12° and a inclination of 15° (this is the position at University). The total estimated budget for this facility would be approximately € 108,117.

Figure 5 shows a drawing with a simulation of what would be the parking structure with photovoltaic modules on top.

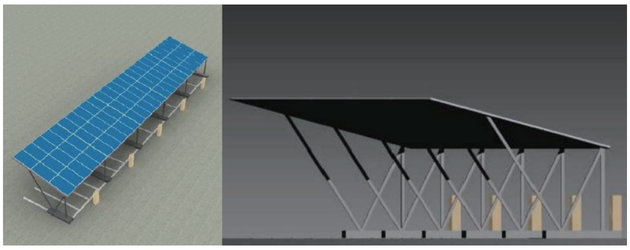

Figure 5
Simulation With Autodesk Inventor of a Photovoltaic Parking

3.2 Economic Analysis

3.2.1 Investment and Depreciation of Both Photovoltaic Installations

For this analysis it has been considered a CPI (Consumer Price Index) of 3% and an electricity price of 0.177 €/kWh[10] . For an installation on family house it would be repaid after 11 years with a cumulative savings of 11,476 € after 25 years of life.

In Tables 1 and 2 can be seen the economic analysis of an installation on a house and on a parking, respectively. In the case of the parking facility it would be amortized after 9 years, reaching a final saving of approximately 91,427€ after 25 years of life.

The first conclusion is that there is not any variation between to purchase the power to the company or to acquire our own energy through a photovoltaic system when de distance traveled is 25-50km.

In mostly of cases the payback time is slightly the same recharging with photovoltaic or buying energy. For example using the Renault Kangoo ZE vehicle, driving 50 km daily, the payback time in our analysis is the same. Only using a Vetrix VX-2 years for amortization are between 0.25-0.5 higher recharging with PV than buying energy.

Secondly we see variable results depending on vehicle used and the kilometers derived. In any case it can be seen that the more kilometers are derived, the VE takes greater advantage over the combustion equivalent. It also influences the type of vehicle used, the payback time for a moped or motorcycle is lower due to a lower initial investment. The major disadvantage of the Electric Vehicle is its high purchase price. However for a long term considerable savings can be obtained in many cases.

[5] http://www.nissan.es/ES/es/vehicles/electric-vehicles/leaf.html#vehicles/electric-vehicles/leaf
[6] http://www.siliken.com
[7] SMA Solar Technology. http://www.sma-iberica.com/es.html
[8] http://www.siliken.com
[9] SMA Solar Technology. http://www.sma-iberica.com/es.html
[10] http://www.cne.es/cne/doc/publicaciones/CNE_InformeComparador.pdf

Table 1
Amortization of a Family Housing Installation

				Expenses				
Year	**kWh**	**(€/kWh)**	**Money saved**	**Amortization**		**Cost**	**Balance year**	**Accumulated**
0				**Capital**	**Interés**	5.527,2	5.527,2	
1	3.816	0,177	673,6	390,7	414,5	53,9	185,5	5.322,0
11	3.451	0,237	818,7			72,4	746,3	558,2
12	3.417	0,244	834,8			74,6	760,2	202,0
24	3.028	0,348	1.055,0			106,4	948,7	10.509,8
25	2.998	0,359	1.075,8			109,5	966,3	11.476,1
	84.783		21.493,2	5.527,2	2.525,2	1.964,7	5.948,9	

Table 2
Amortization of Installation in Parking

				Expenses				
Year	**kWh**	**(€/kWh)**	**Money saved**	**Amortization**		**Cost**	**Balance year**	**Accumulated**
0				**Capital**	**Interés**		24.688,3	30.860,4
1	26.100	0,177	4.607,2	1.745,1	1.851,6	368,6	641,9	28.473,4
9	24.084	0,224	5.385,3	3.112,4	484,4	466,9	1.321,7	746,2
10	23.843	0,230	5.161,4	3.345,8	250,9	480,9	1.413,8	4.013,4
24	20.713	0,348	7.216,1			727,4	6.488,6	84.818,8
25	20.506	0,359	7.358,2			749.2	6.609,0	91.427,7
	579.886		147.005,1	24.688,3	11.2791,	13.437,9	72.911,5	

3.2.2 Amortization Periods of Several Vehicles

Table 3 shows the amortization period of the vehicles tested:

Table 3
Vehicles Amortization

		Years for Amortization VE	
Case	**Vehicle**	**To buy energy**	**Recharage FV**
	Renault Kangoo ZE	+VE*	+VE
	Nissan Leaf	11	11
25 km	Citroen C-Zero	+VE	VE
	Vectrix Li VX-1	6,5	6,5
	Vectix VX-2	2,5	3
	Renault Kangoo ZE	12,5	12,5
	Nissan Leaf	6	7
50 km	Citroen C-Zero	9,5	9,75
	Vectrix Li VX-1	3,25	3,75
	Vectix VX-2	1,5	1,75
	Renault Kangoo ZE	7,25	9
	Nissan Leaf	3	4,75
100 km	Citroen C-Zero	5	6
	Vectrix Li VX-1	1,5	2,25
	Vectix VX-2	0,75	1

*+VE: The electric vehicle (VE) is more expensive.

3.2.3 Saving

Table 4 shows the money saved after the 15 years of life of the vehicle:

Table 4
Savings After 15 Years of Use of Vehicles Analyzed

		Money Saved After 15 Years (€)	
Case	**Vehicle**	**To buy energy**	**Recharage FV**
25 km	Renault Kangoo ZE	-6.126,9 €	-5.807,8 €
	Nissan Leaf	2.359,5 €	3.149,6 €
	Citroen C-Zero	-1.746,3 €	-1.129,7 €
	Vectrix Li VX-1	5.684,8 €	5.913,2 €
	Vectix VX-2	4.700,2 €	4.770,4 €
50 km	Renault Kangoo ZE	1.330,2 €	1.968,4 €
	Nissan Leaf	10.172,8 €	11.753,1 €
	Citroen C-Zero	7.587,5 €	8.820,6 €
	Vectrix Li VX-1	14.761,4 €	15.218,2 €
	Vectix VX-2	10.247,3 €	10.387,8 €
100 km	Renault Kangoo ZE	8.684,4 €	9.960,8 €
	Nissan Leaf	25.799,4 €	28.959,9 €
	Citroen C-Zero	26.254,9 €	28.721,2 €
	Vectrix Li VX-1	32.914,7 €	33.828,3 €
	Vectix VX-2	21.341,6 €	21.622,6 €

It is striking that in some cases the savings after 15 years can reach almost to 30,000 € (80% of savings compared to its equivalent with combustion).

It can also be seen that the photovoltaic system gets higher savings compared to buying the energy. Using an electric Nissan Leaf and recharging with solar photovoltaic panels 3,160€ more will be saved in comparison to buying the energy.

3.3 Emissions Analysis

The emissions produced by combustion vehicles can be of two types: direct or indirect. Direct emissions are from power generation in the motor vehicle, while indirect emissions refers systems involved in the generation of fuel, and they are approximately a 15%.

Emissions from electric cars would be about 0.26 kg CO_2/kWh[11]. If the energy comes from renewable energy sources, such as the photovoltaic power project proposed in this article, emissions would be nearly zero.

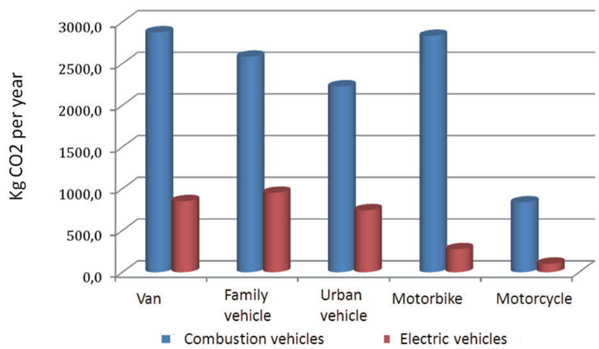

Figure 6
Pollutants Emissions: Combustion Vehicles Versus Electric Vehicles

[11] http://assets.wwf.es/downloads/oe_julio_2011_02082011.pdf

Figure 6 shows a graph comparing emissions from vehicles analyzed, considering a distance of 50 km drowned daily and non-renewable energy recharge. It can be seen a great difference in emissions without using clean energy.

CONCLUSION

After this study it can be concluded that the electric vehicle is cost-effective in most of the cases analyzed, but it varies greatly depending on many factors such as type of vehicle, the distance traveled daily, the initial investment, the electric vehicle consumption and its fuel-vehicle equivalent. In any case it can be seen that when a higher mileage driven the EV takes greater advantage over the combustion-vehicle equivalent.

The main benefits and advantages of using EV are:

• Null noise

• Pollution and CO_2 emissions. In any type of electric van, vehicle, motorbike or motorcycle CO_2 emissions is less than a third compared to its combustion equivalent

• An improved efficiency of the electrical system, it can be seen the demand curve is stabilized, the large differences that occur between periods of higher and lower power consumption are reduced.

• It facilitates integration of renewable energy into the system safely.

• Electric cars are new consumers and it is expected that in the next decade they will represent approximately a 2% of the demand.

• The electric car can be, in long-term, a reversible electric storage system.

Finally it should be noted that in the next years it will be seen a significant development of this type of vehicle, nowadays many companies are already offering pure electric vehicles. Hybrids are having a good acceptance in the market; these will be the transition to an electric mobility and a sustainable future.

The economic survey demonstrates that:

The case of recharging an electric vehicle with the parking facility is a more profitable investment in comparison to the installation on family house. The first one would be amortized after 9 years, reaching a final saving of approximately 91,427€ after 25 years of life, and the second one would be repaid after 11 years with a cumulative savings of 11,476 € after 25 years of life.

Comparing different types of electric vehicles the payback time is slightly the same, recharging with photovoltaic or buying energy, when 25km or 50km per day are usually driven. But when the distance travelled per day is 100km the amortization time reach to higher periods and depends on the vehicle used. So to take advantage of these solar-charging opportunities, your daily commute destination should be close to a charging station.

The major novelty of this study is the combination of photovoltaic and electric vehicles. It has been demonstrated that using electric vehicles and recharging with solar photovoltaic panels will provide higher saving compared to its equivalent with combustion and higher savings compared to buying the energy. The savings after 15 years can reach almost to 30,000 € (80% of savings compared to its equivalent with combustion). And also recharging the EV with photovoltaic system will provide even 3,160€ more savings compared to buying the energy.

Finally the use of an electric Nissan, a Citroen or Vetrix for long distances traveled per day and recharging with solar photovoltaic panels installed on a parking is suggested for a good investment.