International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 5 Issue 9 ǁ September. 2017 ǁ PP. 11-17

Driving Solar-Battery Cars with Solar Array-Trailers Along Medium-High Slopes with Ultra-Efficient Solar-Arrays

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ABSTRACT: Solar-battery cars have been designed, manufactured by universities and tested by world competitions. The concept of solar array-trailers of various configurations attached to solar-battery cars, in order to increase the acquired solar energy, has been the subject of numerous publications. One of the most challenging tasks in the use of solar-battery cars is driving along medium to high slope terrains. With the advancements in the solar array technology, efficiencies of 40% are close to being achievable, at least in the lab. This paper looks at the implications of such advancement in tackling the challenge of driving along medium to high slope terrains. Two such drive-simulations are discussed. One drive is from Lakes Entrance to Thredbo Village in Southern Australia and the other from Beirut to Dahr-el-Baidar in Mount Lebanon. A summary of the results is also presented.

Keywords: Solar-battery Car; Solar Energy; Solar Array-Trailers; Multi-junction Solar Cells; Medium/high Terrain Gradients

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Date of Submission: 12 -09-2017 Date of acceptance: 23-09-2017

I. INTRODUCTION

Finding an alternative source of energy to gasoline in the transportation sector is driven by either environmental requirements or long term planning. Solar-Battery, Electric as well as Hydrogen fuel cells vehicles are seen as alternative to gasoline cars in the transportation sector [Calsol; Eleanor; Stella; Elshafei et al, 2016; Alavi et al., 2017; Faria et al., 2012, Carroll, 2003; Thacher, 2010]. However, the above solutions either lack in the energy available at the wheels, such as the case of solar-battery cars, or the need for external renewable sources of energy for charging, such as the electric car [Alavi et al., 2017; Chandra Mouli et al, 2016; Faria et al., 2012; Pfenninger et al., 2016]. Attaching solar array-trailers to solar-battery cars increase the input solar energy and, thus, the savings in driving energy. Of course, this is achieved at the expense of a lower driving speed. Detailed studies on the use of solar-battery cars with solar array-trailers along low gradient terrains were discussed in Kasti [2015, 2016, 2017]. Driving solar-battery cars along medium/high terrain gradients is one of the most challenging tasks. With the advancements in the solar array technology, efficiencies of 40% are close to being achievable, at least in the lab. This paper looks at the implications of such advancement in tackling the driving challenge along high to medium slope terrains.Two such drive-simulations are performed. One is a drive from Lakes Entrance to Thredbo Village in Southern Australia and the other from Beirut to Dahr el Baidar in Mount Lebanon. The paper concludes with a summary of results.

II. ROAD DATA, CAR AND SOLAR ARRAY-TRAILER PROPERTIES

Fig. (1) shows the solar-battery car and solar array-trailer configuration. The response of two car types are studied as described in Table 1. Two environments are used in the simulations and summarized in Table 2.

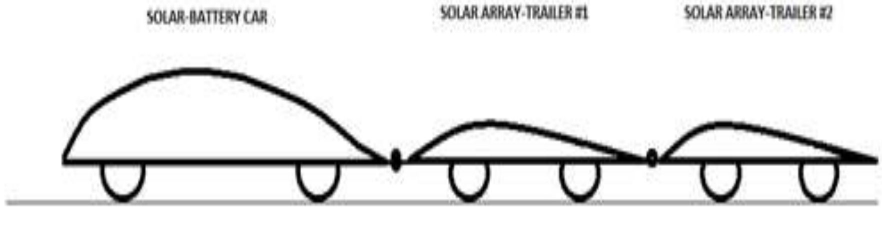

Fig. 1 Solar-battery car with solar array-trailers

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Table 1. Types of cars and trailers

		Car				Trailer		
Type no.	Mass (kg)	$C_dA_d(m^2)$	C_{rr}		Masst (kg)	$C_dA_{dt}(m^2)$	C_{rrt}	Solar Array size
I	500.	3*0.12	0.01		100.	0.12	0.0055	$2x4m^2$
II	300.	0.12	0.0055		100.	0.12	0.0055	$2x4m^2$

Types I&II were used with 13-20% solar array efficiencies in Kasti [2015, 2016 & 2017].

Table 2. Environment of the drives

I	From Lakes Entrance to Thredbo Village, Australia – medium/high gradient terrain - around 260km drive
II	From Beirut to Dahr-el-Baidar, Mount Lebanon – medium/high gradient terrain - 40km drive

The first and second drives are through medium/high slopes reaching elevations around 1600m and 1520m in over 260km and 40km, respectively. In these two drives, snowy weather is experienced during winter thus limiting the use of solar arrays.
The nomenclature of the different terms is shown in Table 4.

III. SIMULATING DRIVES ALONG MEDIUM/HIGH SLOPE TERRAIN: AUSTRALIAN AND MOUNT LEBANON

Since driving along medium-high slope terrains is one of the most challenging tasks for a solar car, the following two drives are simulated in these sections:
A. Drive along medium/high slope terrain in Australia with a car of type I.
B. Drive along medium/high slope terrain in Mount Lebanon with cars of type I & II.

A. Drive along medium/high slope terrain in Australia with a car of type I.

The drive starts at 7:00am solar time for over 260km, from Lakes Entrance in Southern Australia through route C608 (Gelantipy-Ingebirah-Jindabyne) to near Thredbo Village at an elevation of around 1600m. Lakes Entrance is located at 37.87^{o}S with 4m elevation, whereas Thredbo Village is at 36.50^{o}S and 1380m elevation. Rain is possible throughout the year with snow at Thredbo Village during winter as shown in Fig. 2 [Bureau of Meteorology, Australia]. Twelve weather stations were used in the simulations along the drive.

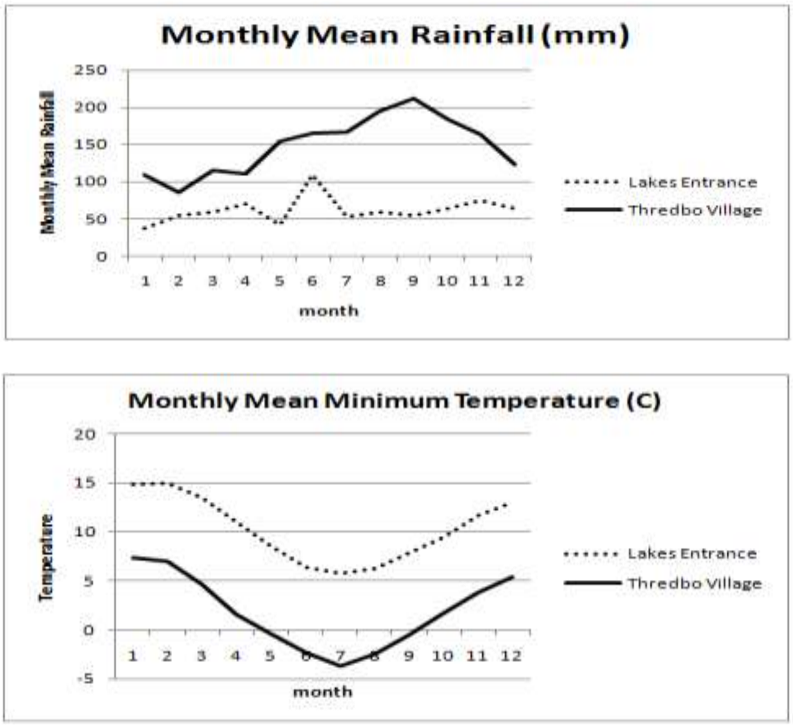


Fig. 2 Monthly mean rainfall and monthly mean temperature at Lakes Entrance and Thredbo Village

Fig. 3 shows the variations in solar energy with higher elevation and the effects of rainy/snowy weather. Fig. 3(a) presents the calculated extraterrestrial solar radiation for both locations without including the effects of elevation. The measured monthly mean daily solar energies are shown in fig. 3(b). The ratios of monthly mean to extraterrestrial solar energy are shown in fig. 3(c). The drop in solar energy at Thredbo Village during increased rainy/snowy months is obvious for the months of June to September. The ratio of monthly mean of daily solar energy to extraterrestrial solar energy varied between 0.3 and 0.6.
The monthly mean of daily solar energy, for all years, was used to determine the factors to be applied to the solar energy equation [Kasti, 2017].
The cumulative energy for the "typical" day of each month is plotted in fig. 4 for a car, and a car with two trailers. Three speeds were used: 25, 40 and 50 km/h.

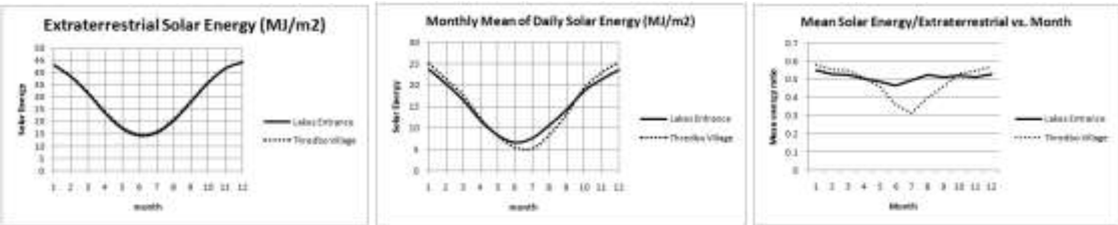


Fig. 3 Extraterrestrial/mean solar energies and ratio of mean to extraterrestrial solar energy for Lakes Entrance and Thredbo Village [Bureau of Meteorology, Australia]

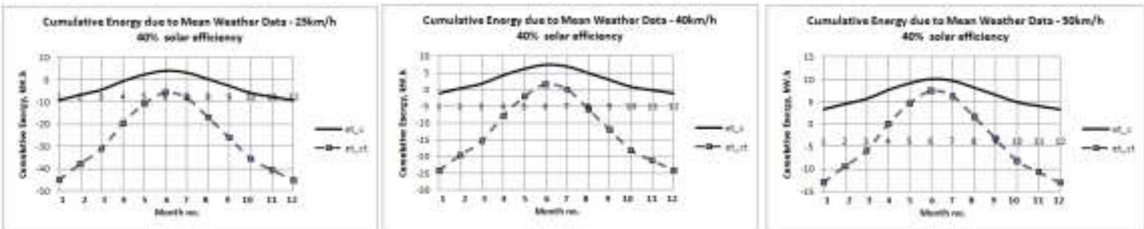


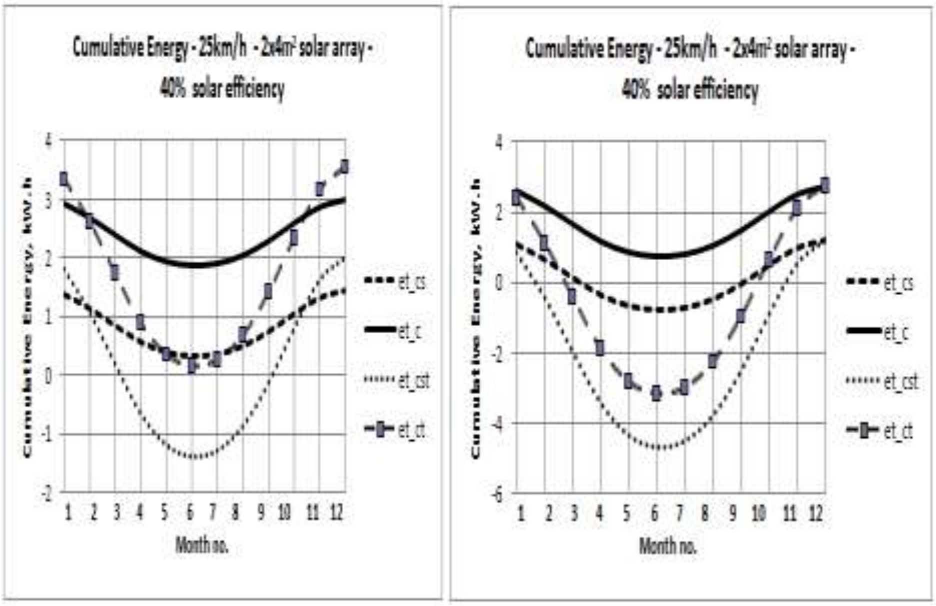
Fig. 4 Variation of the cumulative energy with the month of the year for a car and a car with two trailers for the speeds of: 25,40 and 50km/h

At mean solar energy, a car would use battery power between the months 5-8 at 25km/h, months 2-10 at 40km/h and all year at 50km/h. For a car with two trailers, no battery power usage at 25km/h, around June at 40km/h and between months 5-8 at 50km/h.

B. Drive along medium/high slope terrain in Mount Lebanon with cars of types I and II.

The drive from Beirut (33.90^{o}N and 3m elevation) to Dahr-el-Baidar (33.81^{o}N and 1520m elevation), in Mount Lebanon, is 40km long reaching an elevation of 1520m. The weather during winter is rainy with snow at higher elevations, whereas precipitation is almost nonexistent during the summer months. The monthly average daily solar energy during the summer is close to the range of 61-77% of the extraterrestrial solar energy and, 38-54% during winter [Dawtec; Mourtada, 2011], depending on location. Based on this, two values of solar energy were used in the calculations, namely, 40% and 70% of extraterrestrial solar energy. Obviously, day to day values would vary depending on local weather conditions.
Two starting times for the drive were chosen in the analyses, namely, 7:00am and 12:00am solar times. The results of the simulations are plotted in figs. 5-6 for 40% solar array efficiency and 7-8 for 20% solar array efficiency, as shown below.

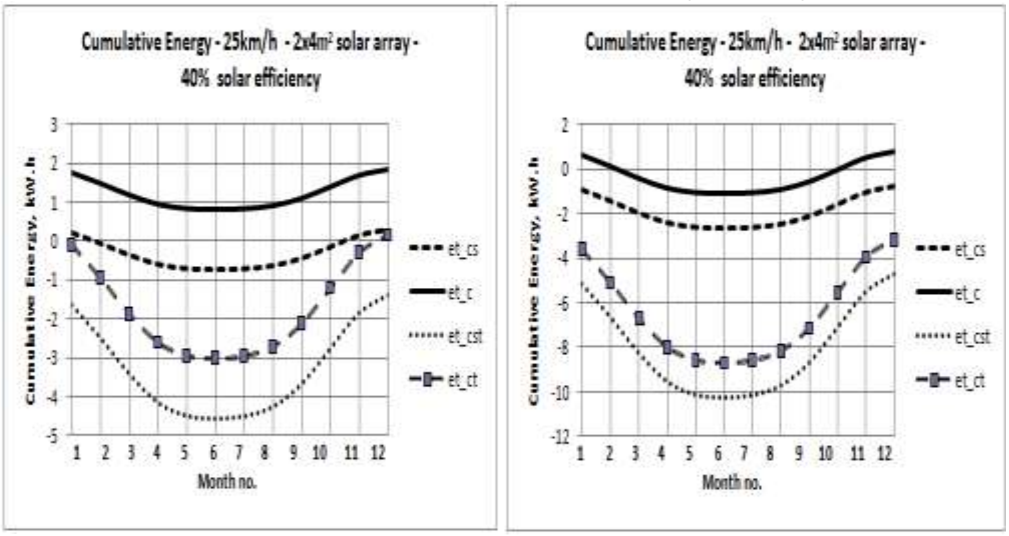
Drive at 7:00am solar time and 40% solar array efficiency:



(i) (ii)

Fig. 5 Variation of the cumulative energy with the month of the year for a car/'race' car with/without two trailers, a 2x4m^2 solar-array, 40% solar array efficiency, speed of 25km/h and,
(i) 40% extraterrestrial solar energy (ii) 70% extraterrestrial solar energy

Drive at 12:00am solar time and 40% solar array efficiency:



(i) (ii)

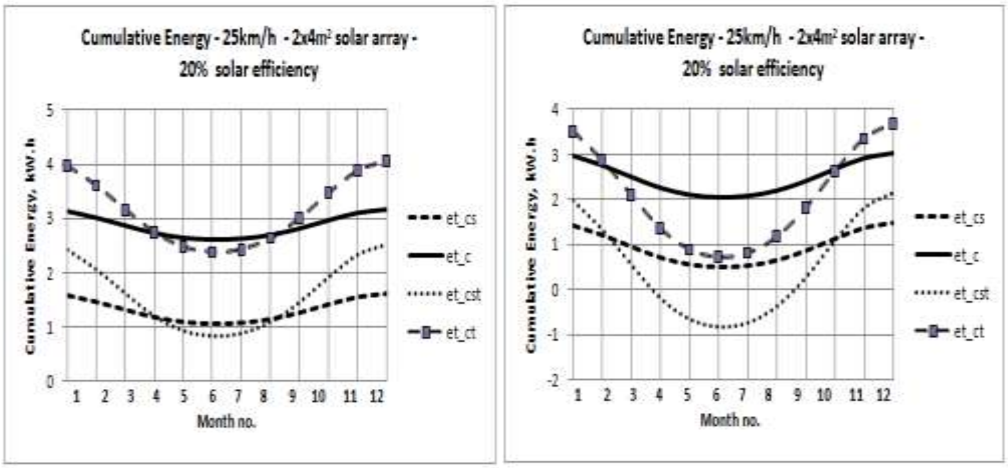
Fig. 6 Variation of the cumulative energy with the month of the year for a car/'race' car with/without two trailers, a 2x4m^2 solar-array, 40% solar array efficiency, speed of 25km/h and,
(i) 40% extraterrestrial solar energy (ii) 70% extraterrestrial solar energy

For the 7AM drive, car/'race' cars with trailers have advantage over car/'race' cars for months 2-10 at 40% of extraterrestrial solar energy and months 1-11at 70% of extraterrestrial solar energy. For the 12AM drive, car/'race' cars with trailers have advantage over car/'race' car throughout the year at 40% and 70% of extraterrestrial solar energy. Battery power is rarely used by car/'race' car with trailers throughout the year.

It is worth noting: for some months of the year and for the high ground gradients four wheel drives on the solar-battery car may be necessary. This would be needed to increase the ground traction.

The results of the above calculations are repeated for 20% solar array efficiency as shown in Figs. 7-8.

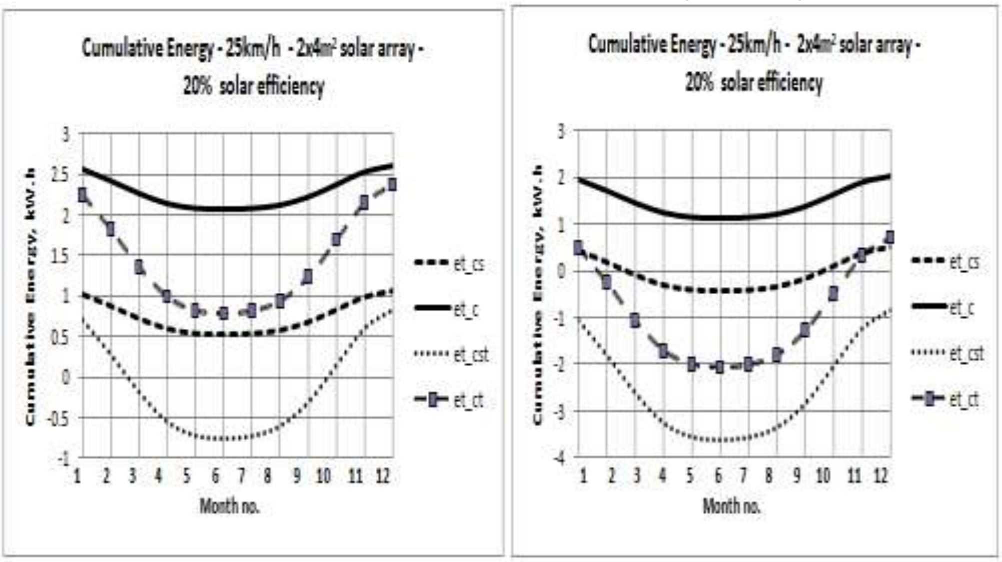
Drive at 7:00am solar time and 20% solar array efficiency:



(i) (ii)

Fig. 7 Variation of the cumulative energy with the month of the year for a car/'race' car with/without two trailers, a 2x4m^2 solar-array, 20% solar array efficiency, speed of 25km/h and, (i) 40% extraterrestrial solar energy (ii) 70% extraterrestrial solar energy

Drive at 12:00am solar time and 20% solar array efficiency:



(i) (ii)

Fig. 8 Variation of the cumulative energy with the month of the year for a car/'race' car with/without two trailers, a 2x4m^2 solar-array, 20% solar array efficiency, speed of 25km/h and, (i) 40% extraterrestrial solar energy (ii) 70% extraterrestrial solar energy

By comparing figs. 5-8, one concludes that:

a) At 20% solar array efficiency, battery power is needed in most cases except around 12 AM, with high solar energy levels and with solar array-trailers.

b) At 40% solar array efficiency, solar-array trailers would provide battery savings at 7AM drives and increased savings at 12AM drives.

Cloudy/snowy weather conditions would greatly reduce the daily solar energy input. For average weather conditions, solar-array trailers at 40% solar array efficiency could provide battery-free usage throughout the year on steep slope terrains, such as Mount Lebanon.

IV. CONCLUSIONS

Driving solar-battery cars along medium/high terrain gradients is one of the most challenging tasks. With the advancements in solar array technology, efficiencies of 40% are close to being achievable, at least in the lab. This paper looked at the implications of such advancement in tackling the driving of solar-battery cars with solar array-trailers along medium to high slope terrains. Two drives were simulated. One along medium/high terrain gradients in Southern Australia and the other in Mount Lebanon where Fall/Winter months considerably reduce the available solar energy. Mean solar energy data were used in the calculations. On average, solar-array trailers at 40% solar array efficiency could provide battery-free usage throughout the year on steep slope terrains, such as Mount Lebanon.

APPENDIX

A. Efficiencies of solar cells

Table 3 contains a partial listing of ultra-efficient solar cells as reported by the National Research Energy Laboratory (NERL, 2016) and discussed in Razykov et al. (2011).

Table 3 Efficiencies of Solar Cells

Cell Type	Efficiency, %
Silicon Monocrystalline	25
Single-Junction GaAs:	
Single crystal	27.5
Thin-film crystal	28.8
Multi-junction Cells	
Three-junction (Sharp)	37.9
Four-junction (Boeing)	38.8

B. **Table 4**: Nomenclature of the Car-Trailer system

C_dA_d	Drag Area coefficient (m^2).
C_{rr}	Rolling resistance coefficient of the car.
C_{rrt}	Rolling resistance coefficient of the trailer.
et_c, et_ct	Cumulative energies of a car, and a car with two trailers, respectively.
et_cs,et_cst	Cumulative energies of a 'race' car, and a 'race' car with two trailers, respectively.

REFERENCES

[1]. Alavi, F., Lee, E., van de Wouw, N., De Schutter, B., Lukszo, Z., 2017. Fuel cell cars in a microgrid for synergies between hydrogen and electricity networks, Applied Energy, 192, 296-304.
[2]. Bureau of Meteorology, Australia, http://www.bom.gov.au/.
[3]. CALSOL, UC Berkeley Solar Vehicle.
[4]. Carrol, R., 2003. The Winning Solar Car. SAE International.
[5]. Chandra Mouli, G.R., Bauer, P., Zeman, M., 2016. System design for a solar powered electric vehicle charging station for workplaces. Applied Energy, 168, 434-443.
[6]. Dawtec, based on European Commission – Joint Research Center - Institute for Energy and Transport (IET) , http://www.dawtec.com.
[7]. ELEANOR, MIT Solar Electric Vehicle.
[8]. Elshafei, M., Al-Qutub, A., Saif, A., 2016. Solar car optimization for the World Solar Challenge, 13th International Multi-Conference on Systems, Signals & Devices, IEEE, 751-756.
[9]. Faria, R., Moura, P., Delgado, J., de Ameida, A., 2012. A sustainability assessment of electric vehicles as a personal mobility system, Energy Conversion and Management, 61, 19-30.
[10]. Kasti, N., 2015. Exploring the concept of a solar-battery car with single and double solar-trailers, International Journal of Energy Engineering, 5 (4), 113-124.
[11]. Kasti, N., 2016. Solar-Battery Car with Four-Wheels Solar-Array Trailers, International Journal of Engineering Research and Development, 12(11), 39-42.
[12]. Kasti, N., 2017. Ranges of applicability of a solar-battery car with single and double solar-trailers, Solar Energy, 144, 619–628.
[13]. Mourtada, A., 2011, Mediterranean Solar (Hot) Spot – Preparation Phase, based on Lebanese Climatic Atlas.
[14]. National Renewable Enegy Laboratory (NREL), 2016. https://commons.wikimedia.org/wiki/File:Best_Research-Cell_Efficiencies.png
[15]. Pfenninger, S., Staffell, I., 2016. Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data, Energy, 114, 1251-1265.
[16]. Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H.S., Upadhyaya, H.M., 2011. Solar

photovoltaic electricity: Current status and future prospects. Solar Energy, 85, 1580-1608.
[17]. STELLA, Solar-powered family car by TU Eindhoven.
[18]. Thacher, E., 2010. A Solar Car Primer. Nova Science Publishers.

Najib A. Kasti. "Driving Solar-Battery Cars with Solar Array-Trailers Along Medium-High Slopes with Ultra-Efficient Solar-Arrays." International Journal of Research in Engineering and Science (IJRES), vol. 05, no. 09, 2017, pp. 11–17.