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Technical and economical assessment of a multipurpose electric vehicle for farmers

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ABSTRACT

The RAMseS project, under the European Commission's 6th Framework Program, is dedicated to the construction and test of low-power operations based on photovoltaic power and a multipurpose electric vehicle. In the present study, the life-cycle costs and economical indices for the vehicle during its life span were assessed, compared to those of a standard internal combustion engine vehicle (ICEV). The results indicated that the life-cycle costs for the RAMseS vehicle and the ICEV are the same for a fuel unit price of 1.8 €/L. Also, the levelized cost of energy (LCE) for the RAMseS vehicle, was found to be 2.13 €/kWh, while RAMseS LCE, without EV taken into account, was shown to be 0.62 €/kWh. The RAMseS payback period (PBP) without EV taken into account was calculated to be 9 years if the value of the produced energy becomes at least 0.35 €/kWh. Vehicles that use PV systems as their power source, such as RAMseS, will be economically effective for fuel costs higher than 1.8 €/L, but considering the environmental benefits that are provided in terms of external costs, they can be considered profitable even at lower fuel costs.

1. Introduction

Concerns about the gradual depletion of the fossil fuel reserves, as well as about climatic changes, have generated a deep consciousness that it is essential for humankind to develop new and clean energy sources. Within this concept, photovoltaic (PV) energy appears to be one of the best choices, especially for highly insolated countries. Many studies have been conducted in order to evaluate the economics of PV systems in comparison to conventional systems. Several of these studies prove the profitability of PV systems [1] but the result depends on several factors, such as equipment costs, final uses, remoteness and connection to the power grid and, in view of a comparison, fossil fuel costs.

In the present paper, the cost of a specific PV system where the generated electric power is used mainly for a specific application such as providing power to an electric vehicle is studied. This is the aim of the RAMseS (Renewable energy Agricultural Multipurpose System for farmers) project financed by the European Commission. The project is dedicated to the manufacturing and testing of a multipurpose agricultural vehicle powered by stationary PV panels, to be used in Mediterranean countries. The basic idea of the project is that the vehicle produces an economic service while also storing the energy that is produced, since in most Mediterranean countries it is not possible to generate profit by selling energy to the grid. In this sense, an electric vehicle provides an immediate and practical technology, better than alternatives such as conventional, hybrid and hydrogen fuel cell vehicles (see, e.g. the work by Granovskii et al. [2] that demonstrates the higher efficiency of electric vehicles). In the previous work, Mousazadeh et al. [3] analyzed the environmental characteristics of the RAMseS project on the basis of a life-cycle assessment. It is found that the RAMseS system is more environmental friendly than an equivalent ICEV. In this study, a similar approach is used in order to perform an economic evaluation of the system in comparison with a conventional vehicle based on an internal combustion engine (ICEV).

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Nomenclature

4WD	4 Wheel-drive
BOS	Balance of system
AF	Annuities factor
ASABE	American Society of Agricultural and Biological Engineers
C_{BOS}	Cost of BOS, [% of C_{PV}]
C_{EV}	EV cost without battery, [€]
C_{EVB}	Cost of EV battery, [€/kWh]
C_{fuel}	Cost of fuel, [€]
C_{ICEV}	Custom cost of ICEV, [€]
C_L	Land cost, [€]
$C_{N\text{-}REC}$	Non-recurring costs of ICEV, [€]
$C_{O\&M0}$	Operation and maintenance cost for first year, [€]
$C_{O\&M}$	Operation and maintenance cost, [€]
C_{PCU}	Cost of PCU, [€/kWp]
C_{PV}	Custom cost of PV, [€/W_p]
C_R	Replacement costs of RAMseS, [€]
C_{REC}	Recurring costs of ICEV, [€]
C_{SB}	Stationary battery cost, [€/kWh]
C_{TSI}	Cost of Tax–Shelter–Insurance, [€]
C_{yfuel}	Yearly cost of fuel, [€]
d	Discount rate, [%]
E	Conversion efficiency of PV
EV	Electric vehicle
EVB	Electric vehicle battery
E_{year}	Yearly collected energy by PV project, [kWh]
G	Generation of electricity in life-cycle, [kWh]
I	Solar irradiation, [W/m^2]
i	Inflation rate, [%]
ICEV	Internal combustion engine vehicle
i_e	Inflation rate of energy, [%]
i_f	Inflation rate of fuel, [%]
LCC	Life-cycle cost, [€]
LCE	Levelized cost of energy, [€/kWh]
L_{EV}	EV life, [yr]
L_{EVB}	EV battery life, [yr]
L_{ICEV}	ICEV life, [yr]
L_{PCU}	Life of PCU, [yr]
L_{SB}	Stationary battery life, [yr]
m	PV O&M cost ratio, [% of C_{PV}]
MPPT	Maximum power point tracker
N	PV life, [yr]
N_{EVBR}	Number of replacements of EV batteries
N_{EVR}	Number of replacements of EV
N_{PCUR}	Number of replacements of PCU
NPV	Net present value, [€]
N_{RICEV}	Replacing number of the ICEV
N_{SBR}	Number of replacements of stationary batteries
PBP	Pay back period, [year]
PCU	Power conditioning unit
P_E	Energy sale price, [€/kWh]
P_f	Fuel unit price, [€/L]
PR	Performance ratio
PV	Photovoltaic
RAMseS	Renewable energy Agriculture Multipurpose System for farmers
SB	Stationary battery
S_{EV}	EV salvage cost, [% of C_{PV}]
S_{ICEV}	ICEV salvage cost, [% of C_{ICEV}]
TSI	Tax–Shelter–Insurance, [% of C_V]
U_{EVB}	Unit cost of electric vehicle battery, [€/kWh]
U_{PCU}	Unit cost of PCU, [€/kWp]
U_{PV}	Unit cost of PV panels, [€/W_p]
U_{SB}	Unit cost of stationary battery, [€/kWh]

1.1. Review of the literature for PV systems economy

The cost of fossil fuels is the main parameter that influences the economics of a PV system. Bouzidi et al. [4] analyzed the life-cycle cost (LCC) of PV pumping in Algeria compared to that energy system commonly used in the same area, named diesel genset (DG). Their economic analysis showed that in the Algerian market, where the price of the fuel is very low, competing is difficult for renewable energy technologies. Bhuiyan et al. [5] found the levelized energy cost (LCE) of residential PV systems in Bangladesh to be about 0.56 €/kWh. In comparison, at a fuel cost of 0.28 €/L the LCE of a petrol (gasoline) generator was assessed to be 0.65 €/kWh. These results are in agreement with those of Nouni et al. [6] who examined several different PV projects in India in the range of 1–25 kWp. They showed that the unit cost of energy varies in the range of 0.42–0.87 €/kWh. The distance from the national power grid is the second element that affects the economic yield of PV systems. Bhuiyan et al. [5] show that the cost of a unit of energy obtained from the grid is larger than that obtained from PV systems when the user is more than 1 km away from the grid. Also, Oparaku [7] compared the LCC of PV and ICE generated electricity for Nigerian villages over a distance 1.8 km from the grid and showed that PV has a remarkable potential as a cost effective electricity production for rural villages applications. The other main item that influences the profitability of PV systems is the initial cost. From this point of view, Ajan Christopher et al. [8] analyzed the policy of a mix of PV and ICE generators for an off-grid site in Malaysia. Their study showed that a cost reduction of PV systems to 1.86 €/W_p can profitably supply the needed electricity. Koner et al. [9] assessed and compared the life-cycle energy costs of photovoltaic and ICE generators for load shedding application in India. The result showed that, within the present market conditions, the cost of electricity production by PV is comparable to or less than that of ICE generated electricity.

An important parameter of PV systems is the payback period (PBP); that is the time needed for the investor to recoup her/his cost. Bakos and Soursos [10] performed a techno-economic assessment of a standalone mono crystalline 6.4 kW$_p$ PV system for a tourist resort in Greece. They found that the PBP of this system is 10.2 years, without economic subsidiary. With a 60% subsidiary, the PBP reduces to 4.1 years. Suwannakum et al. [11] performed a techno-economic assessment of PV/hybrid systems for remote areas in Thailand. They showed that the PBP for these systems is almost 7 years. They concluded that remote area power systems using renewable energy sources optimized with diesel generator back-up can be economically attractive, particularly when environmental benefits are taken into account in the calculation.

2. Materials and methods

The RAMseS, an all solar powered system for Mediterranean countries, uses batteries in two ways. As storage for the PV produced electricity and as power source for a multipurpose agricultural EVs. A schematic diagram of RAMseS project is shown in Fig. 1. The RAMseS PV panels have been installed in a site in the Monastery of Saints Sarkis and Baghos in Ashkout, in Lebanon. According to satellite data [12], the yearly average horizontal radiation in the area is 4.8 kWh/m^2 day.

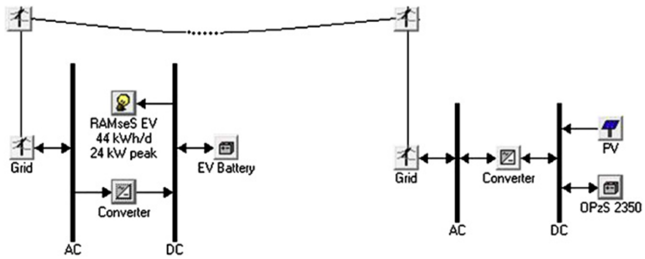

Fig. 1. RAMseS project Schematic diagram.

The mono crystalline silicon PV system has a peak power of almost 12 kW_p and its main parameters are summarized in Table 1. The stationary batteries for storage consist of 23 lead acid single cells in series as modules. These batteries have a long service life and can operate under float charging for 20 years [13]. Therefore, one replacement is expected during the period of 30 years, is considered here. The EV uses two stacks each by 8 batteries; specifications are given in Table 1. RAMseS EV's main DC motor is 12 kW with an auxiliary 12 kW motor.

The parameters examined in the LCC assessment of PV systems are: 1) conversion efficiency (E), 2) solar irradiation (I), 3) performance ratio (PR) and 4) life-time (N). The total life-time electricity generation (G) by the PV modules is calculated as;

$$G = E \times I \times PR \times N \times A = 482500 \text{ kWh}$$

The daily average energy produced was found to be 44 kWh/day.

Since electric motors convert 75% of the chemical energy from the batteries to power the wheels [15], the daily net consumed energy must be reduced to 33 kWh/day.

2.1. RAMseS LCC assessment

The monetary life-cycle cost (LCC) includes all costs necessary to installation, operation, maintenance and replacement during the duration of the project. Therefore, it is one of the best ways to compare the economic performance of different systems. In this case, an electric vehicle powered by PV panels and a conventional vehicle power by fossil fuels were compared. Usually, sum of the initial (C_{ini}), replacement (C_R), operation and maintenance costs ($C_{O\&M}$) are considered as LCC. Hence, the LCC of the RAMseS project (LCC_{RAMseS}) in present monetary value can be shown as follows:

$$LCC_{RAMseS} = C_{ini} + C_R + C_{O\&m} \quad (1)$$

The initial cost of the project is an important factor to investors especially those that are short in financial resources. According to the standard procedure, this cost (C_{ini}) should be calculated as follows:

$$C_{ini} = C_{PV} + C_{SB} + C_{EVB} + C_{EV} + C_{BOS} + C_{PCU} + C_L - S_{EV} \quad (2)$$

C_{PV} is the cost (purchase price) of the PV panels, C_{SB} and C_{EVB} are respectively, the cost of stationary and EV battery, C_{EV} represents the cost of the vehicle, C_{BOS} is the balance of system (BOS) cost, C_{PCU} is the cost of power conditioning unit (PCU), C_L is the land cost and S_{EV} is the salvage value of the EV at the end of its life. It is usual to install PV plants in barren and arid lands not in use or on rooftops (for small projects); therefore, the land cost can be neglected.

The BOS includes the cost of installation and support material while the PCU includes the costs for equipment such as inverter, cabling, rectifier, battery charger and MPPT (maximum power point tracker). According to the literature [16,17] the civil works represent about 40% of price of PV generator for PV part and the engineering cost is almost 10% of PV capital cost. In the present study, it is assumed that the electric RAMseS vehicle is mass produced in numbers comparable to standard ICEVs. Therefore, design and prototyping costs are neglected.

Operation and maintenance costs ($C_{O\&M}$) include tax, insurance, recurring and maintenance costs. Some references [18] suggest that the operation and maintenance cost for PV, BOS and PCU to be zero; but this is an approximation and in the present study we'll make an effort to evaluate these costs. When the discount rate (d) and the inflation rate (i) are the same, the $C_{O\&M}$ parameter can be defined by equation (3-a), otherwise, equation (3-b) should be used [19]:

$$C_{O\&M} = N^* C_{O\&M0} \qquad \text{if } d = i \quad (3\text{-a})$$

$$C_{O\&M} = C_{O\&M0}\left(\frac{1+i}{d-i}\right)\left[1-\left(\frac{1+i}{1+d}\right)^N\right] \qquad \text{if } d \neq i \quad (3\text{-b})$$

where N is the life-cycle period in years. The analysis period is chosen as the service life of the longest-living component. In the case of PV comparison, the PV useful life is chosen as the life-cycle period. Operation and maintenance costs for the first year ($C_{O\&M0}$) are assumed to be a fraction of purchase cost for PV, BOS and PCU [19].

$$C_{O\&M0} = m \cdot (C_{PV} + C_{BOS} + C_{PCU}) \quad (4)$$

where "m" is a ratio between 0 and 1. For battery storage, the annual maintenance and salvage costs are considered to be zero [16].

The discount rate is the factor that describes the changing value of money over time. It is equivalent to the amount of money that can be made with the capital if the money has been invested in a bank. Cost escalation, also called inflation, is used to account for the fact that components and services normally get more expensive over time. In the present study, these factors have been applied to fuel, energy, maintenance costs and replacement parts. Traditionally, fuel costs are considered separately at a higher inflation rate [6]. These parameters are all subjected to strong uncertainties; therefore, in the present study only one inflation rate will be assumed for all items.

The cost calculation for the electric vehicle is based on the data for existing vehicles. It includes the cost of tax, shelter and insurance (TSI) as 1.5%, 0.7% and 0.25% yearly custom cost, respectively

Table 1
RAMseS PV panels and batteries specifications.

	On-board	Stationary
Batteries		
Type	Lead-gel dryfit	Lead acid
Stack Volt	45	48
Stack Ah	180 @ C (5)	1910 @ C (24)
Number in stack	56 (8 * 7)[a]	23
Cycle	700 @ 75% DOD	–
Life-cycle replacement	14	1
Panels		
Cell efficiency (at STC)[b]	17%	
Total panels area (A)	72 m^2	
PR (FF, mismatch, inverter ...)[c]	0.75	
Life-time (N)	30 yr	
Panels installation region	Lebanon	
Yearly average irradiation (I)	1752 $kWh/m^2/yr$	

[a] Although each stack consists of 8 batteries, if RAMseS EV consumes daily produced energy (of 44 kWh/day) almost 7 stacks are used every day (considering 75% DOD).

[b] Standard Test Conditions refer to 1000 W/m^2 solar irradiation, 25 °C cell temperature and Air Mass 1.5.

[c] It was estimated that 25% of energy is lost in the system through PCU conversion efficiency. Losses which accounts for inverter and storage losses [14].

[20]. For TSI calculation, custom cost is not for special year, it is taken as the average over the life-time. Therefore, the annual cost of TSI is 2.45% of the EV custom cost (C_{EV}). If the EV is replaced every L_{EV} years then the cost of TSI in EV life-time (C_{TSI}) is given as ($2.45\% * L_{EV} * C_{EV}$). This cost is added to the EV purchase cost while the salvage cost (S_{EV}) is subtracted. It is assumed that the maintenance cost for EV is zero, since it is very small in comparison to that of a conventional ICEV.

The replacement cost is calculated as a present value of the system. Stationary and EV batteries, PCU and the whole EV are all parts that have to be replaced after some years. The replacement costs are given by Eq. (5) [16].

$$C_R = C_{EVB}\left[\sum_{j=1}^{N_{EVBR}}\left(\frac{1+i}{1+d}\right)^{\frac{N\cdot j}{N_{EVBR}}+1}\right] + C_{SB}\left[\sum_{j=1}^{N_{SBR}}\left(\frac{1+i}{1+d}\right)^{\frac{N\cdot j}{N_{SBR}}+1}\right] + C_{PCU}\left[\sum_{j=1}^{N_{PCUR}}\left(\frac{1+i}{1+d}\right)^{\frac{N\cdot j}{N_{PCUR}}+1}\right] + C_{EV}(1+(0.0245^*L_{EV})-S_{EV})\left[\sum_{j=1}^{N_{EVBR}}\left(\frac{1+i}{1+d}\right)^{\frac{N\cdot j}{N_{EVR}}+1}\right] \tag{5}$$

In Eq. (5) N_{EVBR}, N_{SBR}, N_{PCUR} and N_{EVR} are the number of replacements, respectively for EV batteries, stationary batteries, PCU and EV.

2.2. LCC of an internal combustion engine vehicle (ICEV)

The RAMseS EV can be considered as equivalent to several I-category farm tractors. In this study, we have used the 4WD John Deere 3120 (29.5 hp) well known tractor for comparison.

Total LCC of the ICEV (LCC_{ICEV}) consists of recurring cost (C_{REC}), non-recurring cost ($C_{N\text{-}REC}$) and initial cost (C_{ini}).

$$LCC_{ICEV} = C_{REC} + C_{N\text{-}REC} + C_{ini} \tag{6}$$

The most important recurring cost is that of fuel (C_{fuel}) and it is given as:

$$C_{REC} = C_{fuel} = C_{yfuel}\cdot\left\{\frac{1+i_f}{d-i_f}\cdot\left[1-\left(\frac{1+i_f}{1+d}\right)^N\right]\right\} \tag{7}$$

where C_{yfuel} is the yearly fuel cost and i_f is the inflation rate.

Non-recurring cost include the tractor purchase cost or its replacement cost. Although operation and maintenance (O&M), tax, shelter and insurance (TSI) costs are considered as recurring costs, they are computed here as a percentage of the average of initial cost during the life-time of the vehicle and therefore, are added to non-recurring costs. As mentioned before, in the case of the EV, the cost of TSI per year is almost 2.45% of the purchase cost.

ICEV maintenance includes considerable servicing, mainly due to engine. The main portion of maintenance costs is allocated to oil and filter changing, decarbonization and daily or weekly greasing. Research has shown that the cost of overhauling and maintenance for a 4WD ICEV is about 0.50% of its purchase price per 100 h operation, averaged over the vehicle's life-time [20]. The ICEV will have to be replaced after L_{ICEV} years and we assume that it will work 1630 h per year (more details on this calculation are reported later on). Accordingly, the parameter that describes operation and maintenance costs ($C_{O\&M}$) during the vehicle's life is given as:

$$C_{O\&M}\text{ in ICEV life} = \frac{0.0050^*C_{ICEV}}{100\text{ hr}} * 1630^*L_{ICEV} = 0.08^*L_{ICET}{}^*C_{ICET} \tag{8}$$

C_{ICEV} is the purchase cost of the ICEV. The ICEV life-cycle cost due to replacement, TSI, and overhauling (non-recurring costs) ($C_{N\text{-}REC}$) are described by Eq. (9). The equation can also take into account the salvage value (S_{ICEV}), subtracting it from the initial cost:

$$C_{N\text{-}REC} = C_{ICEV}(1+0.0245^*L_{ICEV}) + (0.08^*L_{ICEV}) - S_{ICEV}\left[\sum_{j=1}^{N_{RICEV}}\left(\frac{1+i}{1+d}\right)^{\frac{N\cdot j}{N_{RICEV}}+1}\right] \tag{9}$$

where N_{RICEV} is the number of ICEVs that have to be replaced during the time scale of the calculation.

Finally the initial cost of ICEV can be estimated as:

$$C_{ini} = C_{ICEV}(1+(0.0245^*L_{ICEV})+(0.08^*L_{ICEV})-S_{ICEV}) \tag{10}$$

2.3. Comparison indicators

The levelized cost of energy (LCE) is one of the commonly used indicators of financial performance in the evaluation of PV projects. It can be defined as the ratio of the total annualized cost of the project to the annual electricity delivered by the project. The method aims at converting the net cash-flow life-cycle costs into a series of annual payments of equal amounts. For a PV plant, the LCE is given by Eq. (11) [16]:

$$LCE = \frac{LCC\cdot AF}{E_{year}} \tag{11}$$

where, E_{year} is the collected energy over a typical year and AF is the annuities factor that is given as:

$$AF = \frac{d\cdot(1+d)^N}{(1+d)^{N-1}} \tag{12}$$

The net present value (NPV) is another indicator that defines the differences between all cash inflows in present values against the present value of all cash outflows associated with the investment project. The NPV is given as [21]:

$$NPV = E_{year}\cdot C_E\left\{\frac{1+i_e}{d-i_e}\cdot\left[1-\left(\frac{1+i_e}{1+d}\right)^N\right]\right\} - LCC \tag{13}$$

where C_E is the unit price of the electricity and i_e is the inflation rate of electricity.

Another indicator that has great importance is the payback period (PBP). It is the length of time that it takes for an investor to recoup the investment. This index is of great importance to private owners or smaller firms that may be poor in cash. The PBP can be estimated as [21]:

$$PBP = \frac{\text{Initial capital cost}}{\text{Annual benefit} - \text{annual O\&M} - \text{annual } C_R} \tag{14}$$

3. Results and discussions

The final fuel efficiency of the ICEV considered here can be estimated from the various losses occurring while the fuel energy is transformed into useful power at wheels. On the average, only about 18% of the fuel energy is transmitted to the flywheel [15]. ASABE has estimated that the energy efficiency for transmission of a typical tractor is around 0.82 [22] leading to a final fuel efficiency of about 15%. At 100% load, the ICEV fuel consumption is 7.18 L/h [23] but, according to EPA data [24], an average load factor equal to 0.59 can be taken into account. Therefore, the average fuel consumption is approximately 4.2 L/h, or 3.6 kg/h considering a density of 0.85 kg/L [25]. Since diesel fuel has an energy density of

Table 2
The value of parameters that are used in this study.

Parameter	Values used	Similar references						
	In this study	[2]	[3]	[5]	[7]	[6]	[27]	[16]
Unit cost of PV panels [€/W$_p$], UPV	3	–	–	3.2	2.2	2.3	4.8	2.6
Stationary battery unit cost [€/kWh], U_{SB}	182	–	–	80	54	–	81	96
Cost of BOS [% of C_{PV}], C_{BOS}	11	5–10	–	4	–	17–47	8	3.2
Unit cost of PCU [€/kW$_p$], U_{PCU}	700	–	–	590	–	515–955	920	964
PV life [year], N	30	–	20	20	30	20	25	25
PV O&M cost ratio [% of C_{PV}], m	1.2	2	1.3	2	3	3	1	1
Discount rate [%], d	12	10	10	7–15	8	10	5	4
Escalation rate [%], i	5.6	–	–	3–8	4	–	–	1.4
Stationary battery life [year], L_{SB}	15	–	–	–	5	7	7	5
Life of PCU [year], L_{PCU}	10	–	7	–	–	10	13	10
Escalation rate of fuel [%], i_f	5.6	0	5	5–10	–	–	–	1.4
Unit cost of EV battery [€/kWh], U_{EVB}	262							
EV purchase cost [€], C_{EV}	15,000							
EV salvage cost [% of C_{EV}], S_{EV}	27							
Tax–shelter–insurance [% of C_V], TSI	2.45							
EV life [year], L_{EV}	15							
EV battery life [year], L_{EVB}	2							
Escalation rate of energy [%], i_e	5.6							
ICEV life [year], L_{ICEV}	7.5							
Purchase cost of ICEV [€], C_{ICEV}	11,250							
ICEV O&M cost [% of C_{ICEV}], $C_{O\&MICEV}$	0.5/100 h							
ICEV salvage cost [% of C_{ICEV}], S_{ICEV}	39							

13.76 kWh/kg, the ICEV daily and yearly consumed fuel can be estimated, respectively, as 16 kg and 5900 kg. With 16 kg/day the ICEV can work 4.47 h per day.

EPA shows that for this kind of diesel agricultural tractors, the expected useful life (median life) is equal to 2500 h [26]. Therefore, it can be assumed that the tractor's useful life is about 1.5 year and after that the tractor must be overhauled or replaced. If the tractor is overhauled four times during its life-time, then, in 30 years, it must be replaced three times. The purchase cost of this ICEV (C_{ICEV}) is 11250 € for year 2008 [23].

Since the RAMseS EV doesn't have as many moving parts as the ICEV, its useful life becomes longer. A 15-year is assumed for the life-time of the RAMseS EV. As shown in Table 2, the Power conditioning unit (PCU) needs to be replaced after each 10 years. The parameters and indicators used in the present study are shown in Table 2.

It is estimated that after 8-year and 15-year, the depreciation of the tractor becomes 61% and 73%, respectively of its purchase value [20]. This estimate also takes into account the effect of inflation. So, it is assumed that the ICEV salvage cost after 8 years is 39% of its initial cost while the EV salvage cost after 15 years is 27% of the initial cost.

When this study was conducted, discount rate, "d" for Lebanon was 12% [28] and the escalation rate of all compared items assumed to be equal to the inflation rate which was reported to be 5.6% in 2008 [29]. The World Bank reports [30] that the price of electric power (C_E) in Lebanon is 0.06 €/kWh for the year considered here. However, for sensitivity analysis (SA), a range of energy prices is considered.

Using the values reported above, one can calculate the LCC and other economic indicators, as shown in Table 3.

From all components of RAMseS initial cost (C_{ini}), almost 38% is allocated to PV, 17% to EV, 16% to SB and also 16% to EVB, 9% and 4%, respectively to PCU and BOS. The replacement cost (C_R) is due to the sum of the factors resulting from EVB, EV, PCU and SB, respectively that is 90%, 2.5%, 5% and 2.5%. The cost for batteries (EVB) and for their replacement is almost 52% of the total RAMseS LCC. These results confirm that for the diffusion of PV systems in the "island" configuration, lowering the battery costs is a priority.

RAMseS economic assessment can be evaluated from two view points. In the first scenario the calculation is carried out for the net energy produced from stationary RAMseS installations without EV taken into account, while in the second scenario the spent energy by RAMseS EV is considered and calculations are performed.

Table 3
Calculated indicators.

RAMseS	
C_{ini}, [€]	97,518
CR, [€]	102,016
$C_{O\&M}$, [€]	8096
LCC, [€]	207,630
LCE, [€/kWh]	
Without EV take in count	0.62
By EV take in count	2.13
NPV, [€]	SA
PBP, [year]	SA
ICEV	
$C_{N\text{-}REC}$, [€]	15,281
C_{ini}	15,682
C_{REC}, [€]	SA
LCC, [€]	SA
LCE	SA

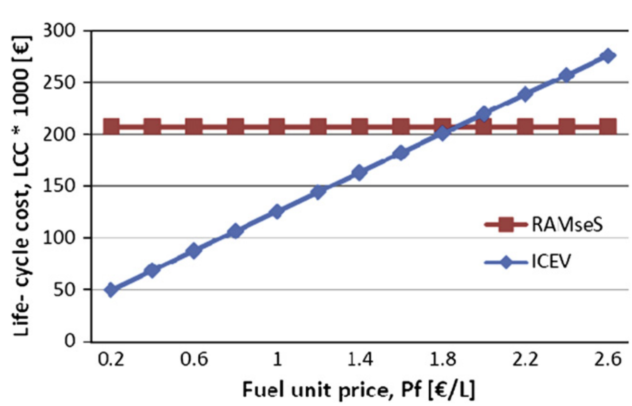

Fig. 2. LCC of ICEV versus fuel unit price and RAMseS LCC.

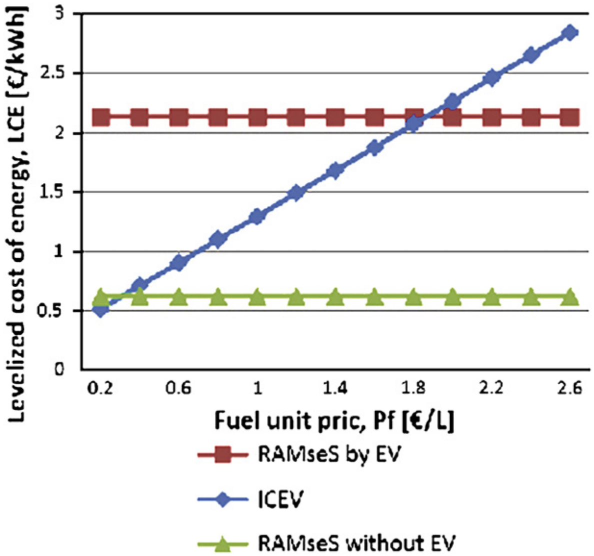

Fig. 3. RAMseS and ICEV levelized cost of energy, LCE.

Obviously, this is the second scenario that must be compared to ICEV.

Fig. 2 illustrates the LCC of the RAMseS project and the compared ICEV. The total RAMseS LCC is almost 207,000 euro for the period considered. While sum of non-recurring costs and initial cost of ICEV is 31,000 euro, its recurring costs and consequently the LCC of ICEV depends strongly on the fuel cost. Increasing fuel cost led to a linearly increasing LCC of ICEV. Parity is obtained when fuel costs are around 1.8 €/L. This figure shows at present, the LCC of RAMseS project is more than an equivalent ICEV, also taking into account that fuel costs are often subsidized for agriculture.

Fig. 3 shows the results of the calculation for the levelized costs of energy (LCE) for two assumptions. In the first case, it is assumed that all the energy produced by the PV system is consumed in the stationary site. Consequently, this case should be compared only to stationary diesel generators that their use is very common for electricity generation in the sites that are far from the grid electricity. In this case the costs related to EV and EVB are not included. This Case led to LCE equal to 0.62 €/kWh. In the second case that is comparable to ICEV, it is assumed that the energy produced by the PV system is all used by the EV. As it is shown in this case, LCE by RAMseS project is 2.13 €/kWh. A value that includes all the costs related to the electric vehicle and the electric vehicle's batteries. Same as LCC, here LCE for ICEV is a linear function of fuel unit price. Increasing fuel unit price increases the LCE. The LCE curve of the ICEV intersects the corresponding curves of case one and case two of RAMseS LCE, respectively in fuel price of 0.3 €/L and 1.8 €/L. Therefore, if RAMseS project is used as an agricultural tractor for farm activities, compared to common tractors, it will be efficient with fuel prices of 1.8 €/L and more, while in stationary applications RAMseS is efficient at fuel prices of 0.3 €/L and more, so stationary applications are already economically competitive for much lower fuel costs.

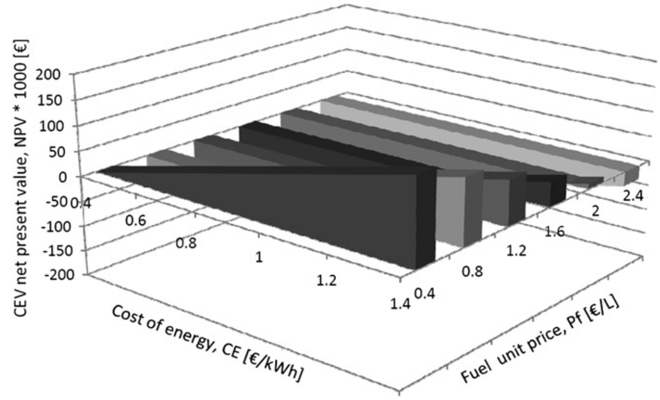

Fig. 5. ICEV net present value versus fuel unit price and cost of energy.

In Fig. 4, the results for the RAMseS net present value (NPV) are shown. Increasing the price of electricity increases the cash inflow and consequently increases the NPV. Here, too, the NPV is calculated considering two assumptions: one, that the energy is used for stationary applications, the other, that the PV system produce energy for the electric vehicle. Again, the calculated NPV is larger when the PV power is coupled to the EV due to the higher investment costs and the need to purchase and replace the batteries. The case of coupling of the EV and the PV system is the one to be compared with the case of the ICEV. For the "stand alone" PV panels (that is, without the EV), if the net energy price falls below 0.35 €/kWh, the NPV for RAMseS will be negative; that is, the owner of the system will never be able to recover his/her own investment cost. For NPV to become positive, when the EV is considered, the energy prices should increase above 1.3 €/kWh. Obviously, the calculations do not take into account the revenues that the EV brings to the farm in terms of agricultural work.

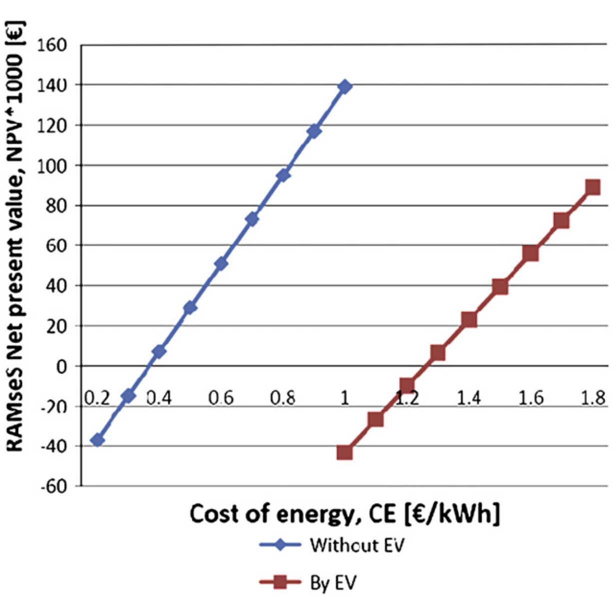

Fig. 4. RAMseS net present value, NPV.

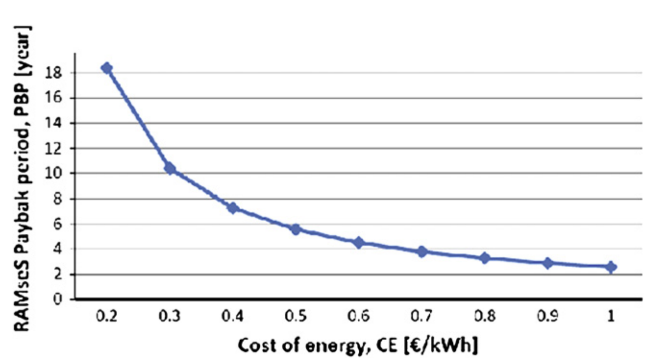

Fig. 6. Sensitivity analysis of RAMseS Payback period.

In Fig. 5, NPV is shown against cost of energy and fuel unit price for the ICEV. If fuel unit price increases above 1.8 €/L, the worth of spent energy must be more than 1.3 €/kWh, in order to ICEV owner recoup his/her investment. From Fig. 4, it is concluded that the cost of spent energy must be more that 1.3 €/kWh, and according to Fig. 5, it is clear that the cost of fuel price should not exceed 1.8 €/L, otherwise, the using of ICEV will not be economical. This graph shows that to compensate the increasing fuel cost, the cost of spent energy must be increased as well, for ICEV NPV to become positive.

The RAMseS payback period (PBP) as a function of net energy cost is shown in Fig. 6. The PBP is of the sum of the years that an investor should wait to recoups the initial investment. Investors prefer short PBPs, especially for those poor in cash. The RAMseS PBP mainly depends on the net energy costs. Increasing net energy cost decreases the PBP. As mentioned earlier, to avoid the negative NPV, the RAMseS net energy cost shouldn't be lower than 0.35 €/kWh. With an energy price equal to 0.35 €/kWh the RAMseS investor must recoup the investment at least after 9 years.

4. Conclusions

The RAMseS project life-cycle costs and economical indicators have been evaluated and compared to those of a conventional internal combustion engine. The analysis showed that the Life-cycle cost (LCC) of the RAMseS project in actualized monetary units is around 207,000 euro – this cost is mainly due to the batteries of the electrical vehicle and to their replacement costs (almost 52%). Therefore, batteries are a critical element of the RAMseS project and it is important to develop more efficient and less costly batteries.

In the present market conditions, the overall performance of an ICEV in economic terms is better than that of the RAMseS. Only when fuel prices reach 1.8 €/L, RAMseS obtains parity with the conventional system. The Levelized cost of energy (LCE) for RAMseS is 2.13 €/kWh and it was shown that it becomes competitive with an ICEV only for a fuel price at or over 1.8 €/L while LCE for RAMseS without taking into account the EV, is 0.65 €/kWh. Our finding is in good agreement with Refs. [5] and [6]. RAMseS and ICEV net present value is a function of energy cost and fuel price. The RAMseS investment can be recovered only if the net energy prices go up to above 0.35 €/kWh and 1.3 €/kWh, respectively for RAMseS without EV and for RAMseS with the EV. Finally, the analysis shows that RAMseS payback period is 9 years in maximum if net energy price does not get lower than 0.35 €/kWh.

Eventually, the effectiveness of RAMseS project is mainly dependent on fossil fuel prices. Oil prices remain highly volatile and it is impossible to predict what will be their trends even in the near future. Therefore, the best assessment of the usefulness of the RAMseS project is not based on fuel costs but on fuel availability. If the world's difficult geopolitical situation leads to a shortage of fuel, then the RAMseS project will always be a good investment.

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