Polish Journal of Agronomy
2009, 1, 15–18

Renewable energy multipurpose system for farmers (RAMseS) – an environmental, technical and economic assessment with a comparison with a conventional thermodynamic vehicle

[1]El Asmar Toufic, [1]Bardi Ugo, [2]Karłowski Jerzy

[1]Università degli Studi di Firenze, Italia
[2]Institute for Buildings, Mechanization and Electrification of Agriculture – Branch Poznań
ul. Biskupińska 67, 60-463 Poznań, Poland

Abstract. The main alternative to reduce the pollution derived from fossil fuels is to replace such fuels by means of renewable energy sources. The applied analysis through life cycle assessment showed that a vehicle powered by renewable energy sources, purely electric, battery driven, has considerable environmental and economic advantages over hybrid and/or conventional vehicles. 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^{-1}, RAMseS obtains parity with the conventional system. The RAMSES investment can be recovered only if the net energy prices go up to above 0.35 € kWh^{-1} and 1.3 € kWh^{-1} respectively for RAMseS without EV and for RAMseS with the EV. Finally, the analysis shows that RAMseS payback period is maximum 9 years if net energy price does not get lower than 0.35 € kWh^{-1}.

keywords: *renewable power, air pollution, electric vehicle.*

INTRODUCTION

During the past two centuries, the great rise of fossil fuels has set unprecedented challenges for agriculture. For one thing, agriculture has become dependent on fossil fuels for fertilizers, pesticides, traction, work and transportation. For another, the release of greenhouse gases from the burning of fossil fuels is creating climate changes which are often unfavourable to agriculture. Agriculture needs to find new solutions to maintain yields compatible with today's solutions. Moving away from fossil fuels means to integrate the modern forms of renewable energy in the agricultural production. The challenge is considerable for several reasons, but mainly it is a question of cost. The problem is especially serious in relatively poor countries (Allal, 2002; Radulovic, 2004; Chehab, Matar, 2001; Lebanese Ministry..., 2001; FAO Solar..., 2000), not only because the cost of the renewable plants in themselves but for the lack of infrastructures that would permit to use the plants at their full potential. The electrical networks of poor countries often cannot reach remote areas and, where this is possible, blackouts are frequent (Chehab, Matar, 2001). When the system is grid connected, static batteries are useless and therefore the whole system has a considerable redundancy with additional costs. The idea of RAMseS is to optimize the renewable power system of farms using batteries not only as storage, but as a mobile form of power to drive an electric vehicle; in this case a multipurpose light tractor with the specific view of utilization in greenhouses. RAMseS is conceived with Southern Mediterranean countries as target areas; given the high solar irradiation of these areas PV is considered as the renewable technology of choice. However, the concept can be extended to small or medium scale windfarms, in northern areas, where there exist favourable sites. This multipurpose system has several advantages for agricultural purposes: 1) it reduces costs by using the same elements (batteries) for two purposes (transportation and power storage); 2) it offers to farms a non polluting, practical and versatile vehicle whose costs do not depend on the vagaries of the oil market; 3) it provides a mobile power source, the vehicle itself, that can be used anywhere without the need of expensive wire networks; 4) it provides protection against blackouts and against the shortage of fossil fuels.

List of Acronyms

RAMseS = Renewable energy multipurpose system for farmers
ICEV = Internal Combustion Engine Vehicle
EV = Electrical Vehicle
PV = Photovoltaic
LCE = Levelized Cost of Energy
GHG = Green House Gases
LCC = Life Cycle Cost
NPV = Net Present Value
LCC = Life Cycle Assessment
PBP = Pay Back Period

Corresponding author:
Jerzy Karłowski
e-mail: jkarlo@ibmer.waw.pl
tel.: +48 61 820 33 31, fax: +48 61 820 83 81

Received 11 December 2009

ELECTRIC VEHICLES IN AGRICULTURE

In the early history of road vehicles, up until the beginning of 20th century, the market was dominated by electric vehicles and only the emergence of cheap gasoline changed the situation. There have been several reported cases of electric vehicles developed and utilized. In the 1930s, both the United States and the Soviet Union experimented with electric tractors. The figure below shows an electric transport vehicle using lead batteries built in the 1970s by IBMER (one of the partners of the RAMseS project) in Poland and used for the transportation of food for cows (Figure 1).

Fig. 1. Electric car for feeding cows, IBMER, Poland.

In this case, the main driving force for the development of an electric vehicle was the need of eliminating pollution from the engine exhaust when the vehicle was moving inside stables. Later on, the development of effective exhaust filters for gas or diesel engine made electric traction less attractive and this vehicle, as well as others that had been developed by IBMER at that time, was abandoned.

On the other side of the world, in the US, the oil crisis of the 1970s had also led to the development of electric tractors. This model, the E15 (Figure 2) built by General Electric was a small tractor operated by conventional lead batteries.

Fig. 2. Electric tractor, General Electric, USA.

The production of this vehicle was discontinued with the fall of the oil prices in the 1980s, the history of agricultural vehicles in western countries was strongly influenced by the world prices of crude oil. At the same time, a new interest in electric agricultural vehicles also reappeared, with many prototypes of light tractors and trucks being built and some offered on the market. Agricultural vehicles might actually be the key that opens up the renaissance of electric vehicles. An electric agricultural vehicle is not affected, or scarcely affected, by most of the drawbacks of electric road vehicles. Agricultural vehicles must be simple and rugged and this is a typical characteristic of electric engines. An agricultural vehicle can afford to be relatively heavy; in some cases it needs to be heavy and it is therefore possible to accommodate the weight of a battery pack large enough to provide sufficient autonomy. Agricultural vehicles are conceived for high torque at low speeds; a characteristic that is easily obtainable with electric engines without the need of the expensive set of accessories (transmission, gears, clutch, etcetera) which are needed for vehicles powered by conventional engines. Electric vehicles are also naturally low pollution ones, and there is no need for the cost and the trouble to shield the agricultural activities from the pollution (gases, oil, fuel, etc.) that is associated with combustion engines. Finally, plenty of space can be found in farms for the installation of renewable energy plants, such as PV panels, and these plants can be naturally "married" to electric vehicles, forming an integrated renewable, energy production, storage and transportation system.

Hence, electric propulsion is especially suitable for agricultural vehicles, as opposed to road ones.

ASSESSMENT AND COMPARISON

The main alternative to reduce the pollution derived from fossil fuels is to replace such fuels by means of renewable energy sources. The simplest and most direct way is to replace fossil fuel powered vehicles with electric vehicles in which power is generated by renewable sources in on-board batteries. Battery-powered electric vehicles are simple, relatively inexpensive, with little emissions and are a technology which is available here and now. The applied analysis through life cycle assessment (LCC) showed that a vehicle powered by renewable energy sources, purely electric, battery driven, has considerable environmental and economic advantages over hybrid and/or conventional vehicles. Our results are in agreement with those of a previous study (Granovskii, 2006). Furthermore, life-cycle costs (LCC) and economical indexes analysis have been applied for the RAMseS Electric Vehicle (EV) during its life time, comparing the results with those of a standard vehicle based on the internal combustion engine (ICEV) (Mousazadeh at al., 2009a).

The studies show that the RAMseS system is considerably more environmentally friendly than conventional

ICEV based system and that, specifically, it can avoid the emission of about 23 ton of CO_2equ per year. (Mousazadeh at al., 2009b). Regarding all other pollutants, we found that the RAMseS system is 2,6 times more efficient than the ICEV. The main contribution to emissions of the RAMseS system is due to the batteries which contribute for a 73% of the total. Therefore, further improvement can be obtained with the use of more advanced battery systems, not based on lead. Technical-economical results indicate that the lifecycle costs for the RAMseS vehicle and the ICEV are the same for a fuel unit price of 1.8 € L^{-1}. Moreover it was shown that if the levelized cost of energy (LCE) for the RAMseS vehicle is considered, the result is 2.13 € kWh^{-1} while with RAMseS LCE without EV it is 0.62 € kWh^{-1}. The RAMseS payback period (PBP) without EV taken into account was found to be 9 years if the worth of the produced energy becomes at least 0.35 € kWh^{-1}. Vehicles that use PV systems as power source, such as RAMseS, will be economically effective for fuel costs higher than 1.8 € L^{-1}, but their use, given the environmental benefits that are provided in terms of external costs, can be considered profitable even at lower fuel costs.

CONCLUSION AND PERSPECTIVES

The LCA calculation conducted for six airborne gases shows that an agricultural vehicle based on the internal combustion engine has much higher emissions than the all-electric RAMseS system (Mousazadeh at al., 2009b). The calculation was conducted only for six airborne gases that present important values of emissions. Calculation results show that ICEV emits 757 ton of CO_2equ to atmosphere in a 30 year life-time, while RAMseS CO_2equ emission is less than 57 ton during the same period (Fig. 3 and 4). It can be concluded by affirming that RAMseS system can prevent 23.3 ton of GHG effects every year. In order to show other environmental effects and also to illustrate the effect of the emission from the two systems on humans the life-cycle was analyzed by using SimaPro software. SimaPro results shows that ICEV is roughly 2.6 times more dangerous than RAMseS. These effects can be translated into monetary units taking into account the direct and indirect costs. For the six airborne gases and some heavy metals considered, the cost impact of the internal combustion system is 4.7 times larger than that of the RAMseS system. This difference between the calculated algorithm and the software is due to the impact of other emissions taken into account in the software. In the calculation method it is shown that PV has the most monetary impact, while SimaPro shows that the battery has the main portion of impact. This is due to Pb emission from batteries that are considered in the SimaPro. It shown almost 73% of RAMseS emission is due to battery, hence, if the battery technology is improved, the impact on the RAMseS system will be noticeable. RAMseS system uses 33.6 ton of lead battery in it's life-time for

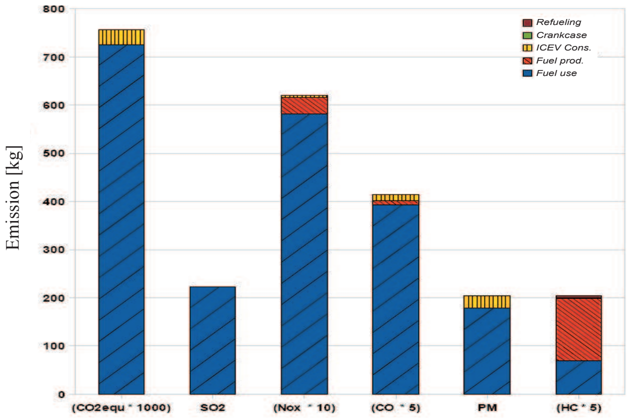

Fig. 3. ICEV life-cycle air pollution.

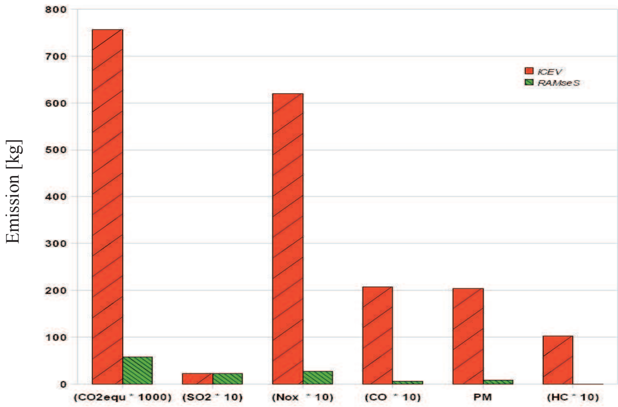

Fig. 4. Comparison between RAMseS and ICEV emission.

which 61% is lead, and it's emission is very harmful from carcinogenic viewpoint. (Mousazadeh at al., 2009b). These calculations are, obviously, affected by uncertainties, however it is obvious that the RAMseS approach carries a major environmental benefit.

From the other part, life-cycle costs and economical indicators were 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 €. This cost is mainly due to the batteries of the electrical vehicle and to their replacement costs (almost 52%) (Mousazadeh at al., 2009a). Therefore, batteries are a critical element of the RAMSES project and it is important to develop more efficient and less costly batteries.

Cost is a critical question: how does it compare with conventional systems? If we calculate the external costs (pollution and global warming) the RAMseS system has a significant advantage. However, these external costs are not paid directly by farmers and, despite the fact that the RAMseS system does not need fuel, there are monetary costs in terms of investment and in terms of the periodic replacement of batteries and other parts. Our calculations indicate that the RAMseS system in its present configuration is slightly more expensive than the conventional, diesel powered system over a life cycle of 30 years. In order to have the same life cycle costs for the two cases – RAMseS and conventional – diesel fuel would have to cost almost or more than 1.8 € L^{-1}. That is higher than the present cost at the pump, even without considering subsidies given to farmers. Nevertheless, this result is encouraging.

In the future, the cost effectiveness of the system may be improved by eliminating the stationary batteries and relying only on the grid as storage, but at present this is not possible in countries where local regulations do not permit it (e.g. Mediterranean Countries). The advantage of the RAMseS system, anyway, goes beyond a simple cost comparison: it lies in being independent from fossil fuels and therefore not sensible to supply interruptions and oil price spikes.

Agricultural vehicles come in many kinds and many shapes; some as large combine harvesters and some as small, hand operated cultivators. The RAMseS vehicle does not pretend to be compared to giant agricultural machines. It has been conceived and designed to be used in a specific environment: in a Mediterranean farm where the main product is grape and/or wine, olive oil, horticulture, etc., where the vehicle will be used for a variety of light agricultural tasks. Because of the specific climatic conditions there, we assume that the vehicle will work for 2–4 hours in the morning, then it will be recharged over midday, when the temperature is so high that it is impossible to work in the fields. In the afternoon, the vehicle will be used again for 2-4 hours and will be recharged again overnight. In the present configuration, the vehicle is expected to be able to perform these tasks, but modifications may be needed for different conditions. If more endurance is needed, for instance, there is space in the present prototype for adding more on-board batteries.

The final question is whether an all-electric, renewable agriculture is really possible. Can we think of an electric combine harvester? Can we plow the fields with electrical tractors? The answer is, "yes, but...". In principle, it is perfectly possible to design and build heavy electric agricultural vehicles such as tractors and combines. But, if we use lead batteries and we want the machine to keep working all the day long, we need a very large battery pack and that would be very expensive. There are many technological possibilities to improve on lead batteries and perhaps in the future the problem of storage will be solved with new possibilities. But, if we have to stay with current technology, we must think of battery powered mechanized agriculture as something more limited than the kind of mechanization we are used to.

It is unavoidable, anyway, that future agriculture will be something very different from what it is today. The problem with modern agriculture is not just that of powering tractors and vehicles. It lies with the need of artificial fertilizers and pesticides, with the erosion of the fertile soil and, not the least, with the emissions of greenhouse gases and the resulting climate change that may damage agricultural yields. For the future, we must think of an agriculture which will not destroy the fertile soil, which will need less (or no) artificial fertilizers and pesticides, and which will be, in general, less polluting and more sustainable. It will not be anymore the kind of large scale, heavily mechanized enterprise we are used to but, likely, a smaller scale operation, more based on local resources. The results of the RAMseS project show that using renewable electric power is a concrete possibility to break away from the present dependency on fossil fuels in agriculture.

ACKNOWLEDGEMENTS

The authors would like to thank all the members of the RAMseS team for their enthusiasm and commitment to this project.

REFERENCES

Allal S., 2002. Mediterranean Countries, Energy efficiency in southern and eastern Mediterranean countries, an imperious need for sustainable development: Challenges and constraints. Helio International, Rio Report.

Analysis of viability of the Clean Development Mechanism in the Mediterranean Area. 2003. The Kyoto Protocol and the Euro-Mediterranean Co-operation; CDM-ANVIMAR – A Guide to the Implementation of CDM Projects in Mediterranean Countries, December 2003, Fabiano Editori.

Chehab S., Matar T., 2001. Energy in Lebanon. Facing the 3rd Millenium, ALMEE.

FAO, 2000. Solar Photovoltaics for sustainable agriculture and rural development. B. van Campen, D. Guidi and G. Best, Environment and Natural Resources, Working Paper No. 2, 76 pp., 21 tables, 10 text boxes, 6 annexes FAO, Rome.

Granovskii M., Dincer I., Rosen M.A., 2006. Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles. J. Power Sour., 159: 1186–1193.

Lebanese Ministry of the Environment. State of the environment Report, 2001.

Mousazadeh H., Keyhani A., Mobli H., Bardi U., El Asmar T., 2009a. Sustainability in Agricultural Mechanization: Assessment of a Combined Photovoltaic and Electric Multipurpose System for Farmers (2009). Sustain. J., 1(4): 1042-1068.

Mousazadeh H., Keyhani A., Mobli H., Bardi U., Lombardi G., El Asmar T., 2009b. Environmental assessment of RAMseS multipurpose electric vehicle compared to a conventional combustion engine vehicle. J. Cleaner Prod., 17(9): 781-790.

Potential and prospects for Renewable Energy Electricity Generation in the ECSWA region. 2001, Vol. I: Overview of Wind and Biomass Systems. 50-54. ECSWA, UN, New York

Radulovic V., 2004. Are new institutional economics enough? Promoting photovoltaics in India's agricultural sector. Energy Polic., 33: 1883-1899.