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Review on applications of electric vehicles in the countryside

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ABSTRACT: *This paper presents the main applications of electric vehicles in rural areas, pointing out the trends and challenges for the future. Technological conditions and difficulties faced by the industry for a wide dissemination of this technology are discussed. The paper described the main researches with proposals to overcome the problems of implementing electric tractors, as supply and electricity storage. Technical and economic comparisons between conventional internal combustion tractors and electric tractors are also presented and discussed. The paper showed the existence of barriers to the implementation of electric vehicles in rural areas, as well as the need for batteries technological evolution, which have high costs and for that reason they are very heavy for these purposes, but there are already systems that can be applied to minimize dependence of fossil fuels in this sector and increase the use of sustainable energy.*
Key words: *electric vehicles, micro tractors, electric tractor, batteries.*

Revisão de aplicações de veículos elétricos no meio rural

RESUMO: *Este artigo apresenta as principais aplicações de veículos elétricos no meio rural, apontanto as tendências e mudanças futuras. O trabalho discute também as condições tecnológicas e dificuldades enfrentadas pelo setor industrial para a inserção do veículo elétrico no mercado. São apresentados os principais pesquisadores da área com propostas para superar os problemas da implementação dos tratores elétricos, tais como abastecimento e armazenamento de energia elétrica. As comparações técnicas e econômicas entre tratores convencionais, a combustão interna, e tratores elétricos são apresentadas e discutidas. A revisão mostra a existência de barreiras para a implantação dos veículos elétricos no meio rural, como a necessidade de evolução tecnológica das baterias, que apresentam alto custo e ainda são pesadas para este propósito, mas mostra também que já existem sistemas que podem minimizar a dependência de compubstíveis fóceis do setor e aumentar o uso de energia sustentável.*
Palavras-chave: *veículos elétricos, microtratores, trator elétrico, baterias.*

INTRODUCTION

Environmental worries such as the fossil fuels reduction, greenhouse gases emission and climatic variations caused by such phenomena have become more frequent. In this context, the adoption of alternative energy sources has been used by researchers, gaining worldwide attention, with the purpose of reducing the dependence on primary energy sources.

The electric vehicle has become an option for the reduction of greenhouse gas emissions, mainly due to the advent of batteries (CASTRO & FERREIRA, 2010). Thus, new studies, project and trends related to electric vehicles gained proportion. According to ROCCO (2010), there is an expectation that the electric vehicles reach the equivalent of 10% of the world market until 2020.

Although it has already been proved the superiority of the electric motor for purposes of urban locomotion compared to a similar gasoline engine for short distances (up to 150km) (SCHWARTZ et al., 2009), many are the challenges so that the electric car becomes popular. Some of these challenges in relation to Brazil were well discussed in the study reported by PERES et al. (2011).

One area in which the electric vehicles have attracted attention is the rural area, in which the activities that require traction force, carried out mainly by tractors, still use combustion engines. Such fact, in

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a great extent is due to the energy density of diesel being about 100-300 times higher than the density of energy from the batteries (MOUSAZADEH et al., 2010). In addition, the low durability of electrical batteries and the long time to recharge reduce the likelihood of electric tractors having significance in the market (MOUSAZADEH et al., 2010).

According to BARDI et al. (2013), the the agricultural process adaptation to the use of renewable energies; although late, is necessary and natural. Currently, the electrical energy has had a secondary role in the agricultural production processes, being primarily used for activities such as lighting, cooling and heating (BARDI et al., 2013).

The present study contextualizes the main applications of electric vehicles in rural areas and their evolution pointing out the trends and challenges for the future.

Application of electric vehicles in the ural areas: state of the art

The main feature of the rural area and the greatest obstacle to the introduction of electrical tractors in farms is a very high demand of torque on engines used in agricultural machinery (MOUSAZADEH et al., 2010).

According to STECKEL & WHITE (2012), the efficiency of agricultural tractors in mechanized operations has drastically reduced the inputs required in the food industry. In this process, the agricultural tractor is one of the most important agricultural inputs, becoming the main source of power for the modern agriculture. STECKEL & WHITE (2012) estimated an economic contribution equivalent to 8% of the USA's Gross Domestic Product due to the agriculture mechanization implemented in tractors.

According to SERRANO (2007), the tractors are usually selected to meet the needs of implements with high power demand such as plow disks and subsoilers, which often lead to tractor oversizing, comparing to the implements that require less power.

According to SILVEIRA & SIERRA (2010), in the performing of comparative efficiency estimates the specific fuel consumption is used in liters per kilowatt-hour (L/kWh), based on the most frequent points of use of the tractor engine. In oversized tractors, equipped with internal combustion engines (ICEs), the energetic efficiency becomes even smaller.

According to MOUSAZADEH et al. (2010), in addition to the energy issue, it should be pointed out that the agricultural tractors equipped with ICEs are responsible for a great share of the air pollution.

However, based on current economic and environmental issues, the automotive industry is driving the production of powered vehicles from alternative sources of energy, such as electric vehicles and hybrids, with the aim of reducing the use of fossil fuels (CARVALHO, 2008).

To assign a parallel with the automobile industry in order to boost the search of vehicles powered by renewable energy sources, a number of patents of tractors, as required by DOWNING JUNIOR (1978), CHRISTIANSON et al. (1987), ORSOLINI (1995), GINGERICH (1998) and EDMOND (2006) confirmed the concern in designing agricultural machinery powered by renewable energy sources. Table 1 exhibits some details about these patents.

Aiming greater efficiency with lower costs and greater sustainability of agricultural operations, PAULA (2014) studied the operational viability of electricity use as a source of power in agriculture.

Table 1 - Details of patents on electric tractors.

Patent	Summary	Traction system
CHRISTIANSON et al. (1987)	Tractor for simple jobs. Hydraulic connection steering wheel.	1 engine DC 50 HP for 4-wheel traction; from 930 - 2750 RPM
DOWNING JUNIOR (1978)	Tractor for grain harvest. It features an internal structure (chassis), local service that takes the grain harvested from the front to the back, where there is a blower that sends the grain to a storage location.	4 induction motors, one for each wheel;
EDMOND (2006)	Vehicle coupled to lawn mower or snow blowers. Controller of motors rotation.	1 DC motor for traction on the front wheels
GINGERICH (1998)	Vehicle for cargo transport. Controller of motors rotation.	2 DC motors for traction on the front wheels
ORSOLINI (1995)	The front end of a vehicle for transport.	2 motors for traction on the wheels (1 single axis)

With this, PAULA (2014) proposed a theoretical setting of tractors moved by electricity, determining their autonomy and operating costs in different power demands. PAULA (2014) concluded that the operational viability of the electric tractor is assured by the values of autonomy reported only for medium and low demands of power with lower levels of motor rotation, in which autonomy over eight hours per day can be achieved. With up to 59% of the power demand, the performance in the drawbar of the electric tractor model is compatible with conventional tractors. Operational energy cost of the model obtained was up to 89% less than that of conventional tractors.

According to RIBAS et al. (2010), the national farm tractors with power less than 111.8kW have mechanical type transmission (sliding and synchronized gear). PAULA (2014) argued that if it was done the conversion from the conventional tractor to electric tractor, a large part of the mechanical transmission could be dispensed, turning the mechanism simpler, composed only by the electric motor coupled to the differential.

The use of a multi-use battery, supplied by a source coupled to the electric vehicle, known as photovoltaic panels (PV), was proposed by MOUSAZADEH et al. (2010). This system also included stationary devices for energy storage. This stored energy can be used in farms, in electric vehicles or sold, making the system completely independent of fossil fuels.

According to MOUSAZADEH et al. (2010), a PV “on board” in a tractor is capable of releasing around 4kWh per day, while the transient power of an electric tractor with two engines series DC (direct current) of 10.5kW synchronized, one on each rear wheel is 60kW for a few seconds, and the power rating is less than 21kW. Therefore, it is important to think of an electric hybrid tractor, with battery and PV, in which the battery stores the excess energy generated by the panel during the day and uses it during the night or in days with little levels of solar radiation. Conversely, it is possible to apply control algorithms to increase the power produced by photovoltaic cells up to 60% (SCHUSS et al., 2012).

Technologies envolved and comparisons

Electric micro tractors

Without the technology required for the development of large size electric tractors, the focus has been on the development of micro tractors. RODRIGUES et al. (2006) implemented and tested three different types of motors, an electric motor of alternating current (AC), a direct current motor (DC) and an internal combustion engine, mounted on the chassis of a micro tractor used in plowing with fruits of coffee plants in drying terraces. Three tests were performed with each of the engines: The first on the concrete pavement with the aim of determining the traction force, power at the drawbar, power consumption and noise level; the second on a terrace, to determine the effort of plowing the grains and energy consumption; and the third was about the displacement capacity in the field. The results demonstrated that the DC motor was 22% higher than the others in terms of the traction force, with 22.6% more power at the drawbar, presenting the lowest hourly energy consumption.

In order to determine the energy cost and operational autonomy in different power demands, PAULA (2014) built an electrical traction, in reduced scale, which presented a performance at the drawbar compatible with the performance of agricultural tractors. The model also presented the best energy cost compared to conventional tractors. The results achieved by PAULA (2014) showed a lower autonomy of the model in reduced scale of 4.5 hours at maximum power supplied to the drawbar (18.76N). With 66.3% of maximum power presented in the drawbar, autonomy was of 8.33 hours, which, according to PAULA (2014), overcomes the conventional workload of 8 hours a day.

According to MOUSAZADEH et al. (2009), the high cost of the life cycle of electrical micro tractors is primarily due to the batteries of the vehicle and their replacement cost (almost 52% of the total price). Thus, the batteries are a critical element to the project, and it is essential to the development of more efficient and less costly batteries.

Table 2 shows a comparison between the electrical motors and the ICEs. Electric motors have more advantages in numbers, than the ICEs, but with a disadvantage that it is crucial for the countryside, which is the offering of reduced torque.

Batteries

The main barriers to the use of electric vehicles, both in rural and urban environment, are related to the battery efficiency. All the technology available in the market does not allow an electric tractor to develop field work similarly to the conventional tractors, because it would require batteries of high cost and size, and those are the reasons for the unfeasibility of a lot of projects in the area.

According to TAN & TIE (2013), five types of batteries suited for road transport are available in the market. Table 3 shows these batteries and their main advantages and disadvantages,

Table 2 - Comparison between electrical motors and ICEs.

Factors	Electric vehicles	------------------Internal combustion vehicles------------------		
	A*	D*	A*	D*
Noise				X
Vibration				X
Source of propulsion per renewable energy	X			
Emission of pollutant gases				X
Provision of high torque		X	X	
Durability of the propulsion source		X		X
Possibility of self-recharge of the propulsion source	X			X
Recharging time		X	X	
Energy density of the propulsion source		X	X	
Motors efficiency	X			X
Cost of propulsion energy				X
Cost of batteries replacement		X		
Simplified mechanism	X			X
Low operational cost	X			X

*A and D mean advantage and disadvantage respectively.

according to TAN & TIE (2013). Features like energy conversion efficiency, service life (in number of cycles), operating temperature, depth of discharge (usually the batteries are not completely discharged), rate of self-discharge and energy density must be considered when choosing which technology should be used (AKHIL et al., 2013).

In 1996, the General Motors introduced the first generation of electric vehicles, which took place in lead-acid batteries and had a range of 90-120km away. The second generation used nickel-metal hydride batteries and could reach approximately 135km away. Emergence of lithium-ion batteries provided longer reach for the vehicle, as well as having low weight and approximately as much as twice the service life of nickel-metal hydride battery (TAN & TIE, 2013).

According to TAN & TIE (2013), the most common and inexpensive battery available in the market is the lead acid. Its main feature is the durability, but it has an energy density too low comparing to the gasoline, which is approximately 100-300 times higher than lead-acid batteries. This makes their use difficult in tractors that require a large amount of energy in a short time.

According to ROCCO (2010), the initiatives in Brazil regarding the development of batteries are encouraging, with approximately 200 products under patent approval process (Database of INPI, reference year 2010) involving the terms "battery" or "capacitor" and a proportional number of scientific articles published.

Systems and methodologies applicable to electric vehicles in rural areas

TOUFI, UGO & JARZY (2009) used solar PV plates coupled to electric micro tractors and a small local plant of renewable energy also PV in order to meet the demand for vehicles and part of the farms demand. The array of photovoltaic panels installed is of small size and its goal is to load a bank of batteries that are stored ready for use by the community of farmers.

According to SHAAHID & ELHADIDY (2008), the technology of solar PV energy is indicated for remote areas. However, a PV system cannot satisfy the daily demand of a city or small villages, because the variations in solar energy, do not coincide with the distribution demand. Therefore, the systems of energy generation must be installed in combination with a storage unit (batteries) to soften the mismatch between the demand and the solar energy generation. The use of the system for generating the diesel fuel along with the PV system and battery reduce the need for storage (REDPATH et al., 2011). Cost of PV system is high compared with the diesel; however, the operating cost of the PVone is smaller. Besides, the PV maintenance requirements are also lower, but their energy availability is highly dependent on solar radiation, which does not occur with diesel.

The electric energy storage consists of a battery with electronic support more or less complex for load control and errors prevention. The storage unit has to store relatively large quantities of energy and manipulate high powers (REDDY et al., 2011).

Table 3 - Advantages and disadvantages of main types of batteries.

Type	Advantages	Disadvantages
Lead-Acid	Durability Low price	Low energy density comparing to gasoline; It harms the environment.
Nickel	Not harmful to the environment.	Low charge and discharge cycle. High production cost
Lithium	Low weight; High specific power, specific energy and energy density; Non-toxic metals; Non-memory effect	High production cost
Zinc-air	High energy density Low production cost	High volume; Low charge and discharge cycle.
ZEBRA	Zero emission of pollutants; High density and energy; High service life; Robustness; Cell failures proof; High resistance to discharges and overcharges; Very low production cost.	High temperature of activity (300-350ºC); Loss of power at rest.

According to REDPATH et al. (2011), batteries of electric vehicles and hybrid electric vehicles (HEV) should provide power and power spikes during the transient stages, being these conditions tough for batteries. To reduce these adverse conditions, supercapacitors associated with batteries have been presented as a promising solution.

The supercapacitors have a high volume and are more expensive than batteries. However, characteristics, such as long time in cycles of operation and insensitivity to room temperature variations (TAN & TIE, 2013), make them good choices for applications that require a large amount of energy storage and supply in repeated quantities (REDDY et al., 2011).

Moreover, the supercapacitors not only are able to be charged and discharged countless times, but they can also be stored with ten times more energy than the conventional electrolytic capacitors. Besides, they have the merit of a fast charging and discharging of energy and a longer life cycle, because of the nature of the electrostatic capacitor instead of chemical reactions (REDDY et al., 2011).

Factors such as the specificity of use, high costs of production of batteries, and even the convenience in using fossil fuels, still delay the use of electric vehicles in a large scale. Therefore, with the aim of intermediating this technological and sustainable development, the HEV began to enter gradually into the market and can leverage the use of these technologies also in rural areas.

A conventional vehicle with an ICE converts the energy stored chemically (gasoline, ethanol, diesel, etc.) into kinetic energy through a complex process and with significant losses of energy. Combining the ICE with a storage system of power supply and a propulsion electrical system, the vehicle can improve the efficiency regading the use of fuel through various means, such as the provision of extra power or energy absorption, allowing the engine to run at its optimal point (REDDY et al., 2011).

REDDY et al. (2011) also mentioned the benefit from the system known as regenerative braking used in HEV. In regenerative breaking the kinetic energy is reused and heat energy recovery needs a more complex system to occur. In brief, when it comes to braking, part of the energy converted into heat through friction can be transformed into electrical energy to recharge batteries (BARTHEL et al., 2014).

This energy recovery during braking also occurs in other situations and not only when the driver activates the brake pedal. The regenerative braking starts its process at the time that the driver removes his foot from the accelerator with the vehicle in motion and it has been largely disseminated in the area, mainly in electric vehicles, as reported by

XU et al. (2016), LIAN et al. (2016), FARJRI et al. (2016) and KO et al. (2015). According to BOCKER (2013), the estimate of the potential of energy storage by regenerative braking is around 10% in real applications. XU et al. (2011) implemented a system of regenerative braking in an electric vehicle using fuzzy logic and achieved an improvement in the autonomy of 25.7% experimentally.

However, a lot of the mechanized agricultural operations are maneuvers operations that require low speeds and also constant speeds, presenting; therefore, so little acceleration and deceleration, in addition to undergoing through a lot of tires friction on the ground and additional forces of agricultural implements. Thus, the potential of energy storage by regenerative braking in agricultural machinery such as tractors is relatively low (BARTHEL et al., 2014).

Another great application of electric vehicles in rural areas, recently adopted by the farmers, mainly for use in precision agriculture, raising images and diagnosis of difficult access areas, is the Unmanned Aerial Vehicle (UAV), also known as drone. ARTIOLI & BELONI (2016) analyzed the feasibility of the use of drones as an alternative technology in precision agriculture, which assists the farmer, administrators and/or agronomists to make more assertive decisions within their property. ARTIOLI & BELONI (2016) reported that there is still lack of information about the use of this technology, such as doubts about the real benefits from the use of this product, difficulties in operationalizing the equipment, regulations of Agência Nacinal de Aviação Civil (ANAC) and also the drone acquisition cost. ARTIOLI & BELONI (2016) also showed that 80% of rural producers who participated in the survey would be willing to hire drone services with the purpose, mainly, to increase their crops productivity, while 78.6% of the participants would hire the drone services with the main purpose of reducing the inputs cost (pesticides).

Following what was mentioned by several authors in this review about applications and technologies in electric vehicles in rural areas, the information transmitted may be incremented with analyzes of factors that drive the implementation of electric vehicles, according to the world environmental, political and economic situation. Figure 1 shows a diagram with the relations among the three main factors that are connected by the focus of study for this review, their main challenges and areas of study that are driven by investments in research in the sector.

In the diagram shown in figure 1 it is clear the main problem of the technology industry: the electric vehicles autonomy; a problem that is connected directly to the batteries, affecting the electric vehicles applications in any environment and making available indirectly the hybrid vehicles studies. Even with this obstacle, the vehicles electrification continues to be driven by the problems generated by excessive consumption and fossil fuels growing.

Also associated with environmental problems and with the objective of solving the barriers in the energy sector, renewable energy sources appear as the supreme importance for the success of electric vehicles in rural areas, especially by the factor of fuel supply and electricity in remote areas.

CONCLUSION

This study presented a review about the electric vehicles applications in the rural sector. The articles, patents, dissertations and theses referenced and discussed show that the use of electric engines in tractors and rural vehicles is still incipient. Even if advanced technologies have already been used in agricultural machinery and equipment, the specificities of use, the implementation high costs of electric vehicles and the convenience of using fossil fuels still hinder the dissemination. For this reason, it is really important for the area that further researches and tests be made with electric vehicles in rural applications.

Despite the use of PV panels as energy source for rural vehicles has gained attention the last few years, it was noticed in the literature related to rural vehicles a lack of information about their degradation, Maximum Power Point Tracking (MPPT) Algorithms, solar radiation angle and area covered by the panels. Further studies in this area are required so that these features must be into account in future studies.

The main barrier to the advancement and; therefore, to the most promising branch of research in the area is the study of new storage technologies and the use of electric energy as batteries, supercapacitors and regenerative braking, so that they can provide and store an amount of energy sufficient to develop with the same efficiency the work undertaken by combustion vehicles.

Future researches should be directed towards the following points: (i) consider the controlled use of more than two energy sources, which must be defined according to the climate of the region; (ii) calculate the energy profile for each agricultural crop; (iii) focus on activities that require little traction, expecting the problem of energy storage will be solved with new possibilities in the future.

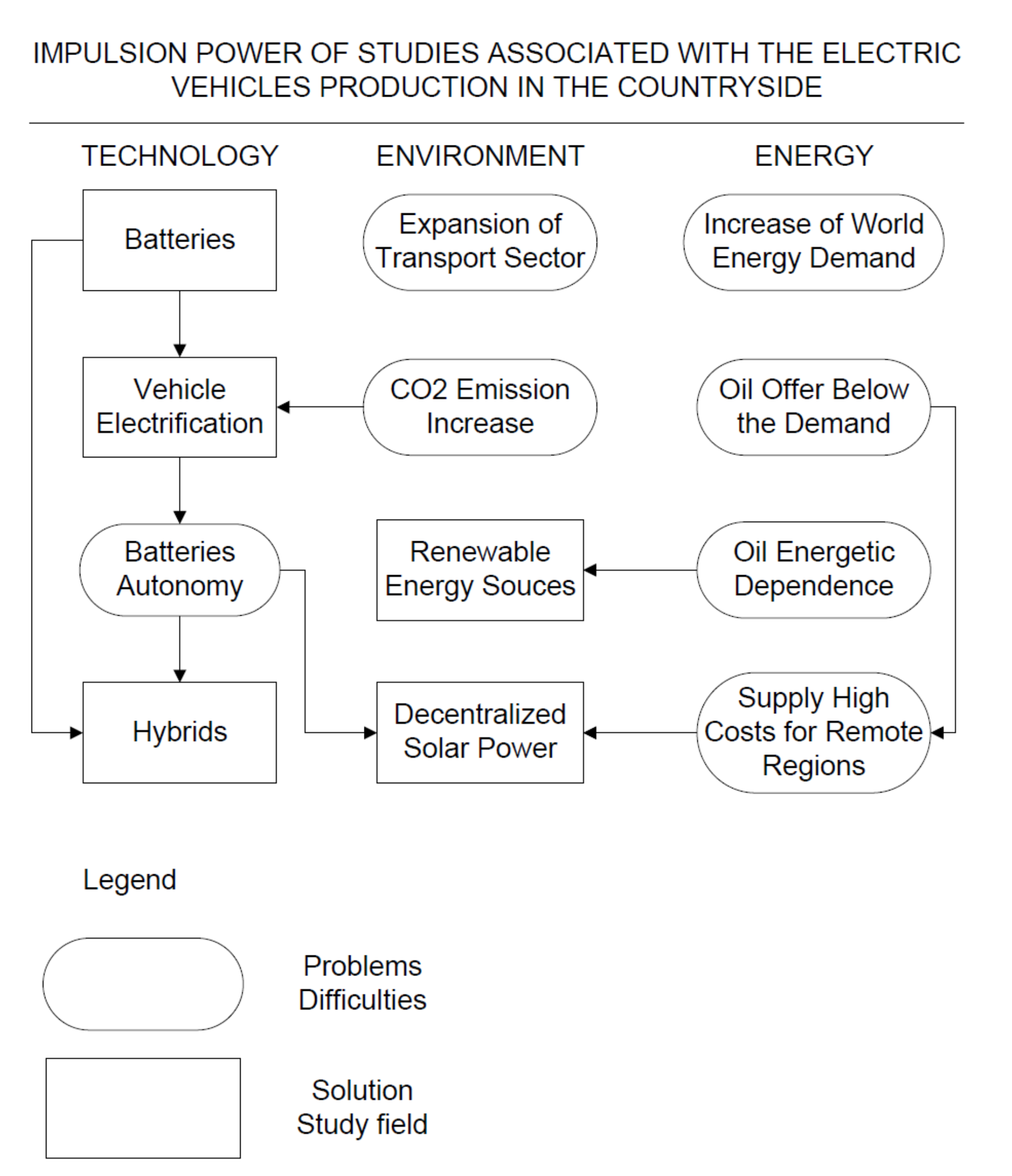

Figure 1 - Impulsion power of the studies applied to the production of electric vehicles in rural areas.

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