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RESEARCH ON THE USE OF PHOTOVOLTAIC SYSTEMS TO POWER OFF-ROAD ELECTRIC TRACTORS

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Abstract: Recent technological development aimed on increasing performances of electrochemical energy storage systems and the new advances of electric motors have created new opportunities for electrical equipment manufacturers in terms of autonomy, performance and stability over time. The development of electric vehicles reported a strong expansion lately, however, electric farm tractors operating in off-road environment are not yet considered interesting for the large equipment manufacturers, due to their high-power operation needs and the small capacity that energy storage systems may offer. One interesting research direction is assessing the opportunity of charging batteries directly in the field, using photovoltaic sources, located close to the land to be processed. In order to address to this important electric vehicle limitation, new technology is needed which will allow the batteries to be charged during the operation of the vehicle, or to recharge near the area to be tilled. Some models are equipped with replaceable battery pack, which can be easily sent on charging and replaced with a new fully charged pack. The present paper examines the ground area requirements for the installation of a photovoltaic station, designed to charge a prototype tractor model, produced by INMA Bucharest.
Keywords: electric tractor, photovoltaic charging, efficiency

INTRODUCTION

Agriculture tractors are usually diesel-powered, contributing to fossil energy consumption, global warming, air pollution and in many cases to soil and groundwater pollution, caused by fuel leakages (*Xue Ji., 2013, Zhang X., 2011*). Recent technological development aimed on increasing performances of electrochemical energy storage systems and the new advances of electric motors have created new opportunities for electrical equipment manufacturers in terms of autonomy, performance and stability over time.

This has allowed car manufacturers to assume major challenges regarding the development of electric or hybrid vehicles, successfully replacing engines that use fossil fuels, while maintaining high levels of performance.

A segment that has not yet managed to reach high levels of performance, allowing to switch from diesel to electrical operation is the industrial field of heavy-duty vehicles, especially those used for agriculture *(Mocera F., and Soma A., 2020)*.

One of the most important problems encountered by electric tractors is that they cannot have the energy density close to a diesel model, that is required to do long, hard work in the field. Performing activities that need high power such as plowing or transporting heavy trailers would drain power much faster from the battery pack (*Choi, S.C. et. al, 2014, Finesso R., 2014, Vaidya A.S., 2019*). Refueling batteries is easily done in the case of agricultural machinery that operates around the farm, but in the case of an agricultural tractor working in the field, returning to the farm is not a viable option.

Diesel equipment can operate continuously for many hours and time periods could be extended even more if will provide a fuel tank in the vicinity of the working area, while battery life is dictated by total loads. In case of heavy loads, the disadvantage of recharging at short intervals, may turn this option into an uneconomical choice.

In order to address to this important electric vehicle limitation, new technology is needed which will allow the batteries to be charged during the operation of the vehicle, or to recharge near the area to be tilled. Some models are equipped with replaceable battery pack, which can be easily sent on charging and replaced with a new fully charged pack. This option of quick exchanging the battery pack minimizes the time required to park the tractor for recharging the batteries, but it also raises negative issues regarding battery management, and increase the cost of having a spare battery pack.

However, when evaluating high energy consuming equipment as agricultural tractors, must consider several other aspects, including the impact on the environment, reducing global fossil fuel consumption as well as CO2 emissions reduction.

While on grid field chargers may provide with the electricity required to manage an agricultural electrical vehicle, many studies agree that the installation of autonomous photovoltaic systems capable of charging batteries should be considered in order to further facilitate the use of renewable energy and to minimize CO2 emissions (*McFadzean B., 2017; Adegbohun Fe., 2019, Dai Q., 2019, Nenciu F., 2014*). This option would be very useful in cases where the electricity network is at a far distance from the plots that are being processed or when the electrical network does not allow overloaded local electricity grids, giving additional flexibility.

There has been little research on local power systems used to recharge batteries used on agricultural tractors, that is why the present article aims to discuss the main problems posed by the large-scale operation of electric tractors, and to objectively evaluate the main ways of feeding electric tractors.

We will first explore how off grid photovoltaic systems can contribute to the charging of electric vehicles according to different geographical positioning, given the maximum potential depending on the location on the globe, the relief forms and the seasonal variations.

Additional benefits could, for instance, be less and additional grid flexibility. Our previous research studies (Matache et. all, 2020), highlighted that in the case of specific tillage that require high operating powers, the electric tractor performing time must be improved in order to be able to process a larger number of hectares.

The method of installing photovoltaic panels directly on the roof of the machine can show some improvement, but has a relative low impact due to the small installation area. Therefore, our objective was to identify and calculate the characteristics of an autonomous photovoltaic system, providing the electric powered supply directly in the field, without the need for changing the batteries.

MATERIALS AND METHODS

Our goal was to determine the area in square meters to be covered by panels to ensure the needed electricity consumption. In order to achieve our goal, the first phase was to determine the power requirements of the electric tractor for various agricultural works, afterwards had to estimate the charging potential of the photovoltaic panels and then calculate the insolation potential depending on the climatic conditions of the area.

In order to calculate the power needed for the plowing process, we have tested an experimental model of agricultural electric tractor, designed by INMA Bucharest (figure 1). The 28,8 Kw electric tractor was equipped with a 17.28 kWh Li-Io battery pack and an ORION battery management system (BMS) that allowed recording the instantaneous power consumption during works. The tractor was equipped with a mechanical transmission of 8 forward gears / reverse shift, having a speed range between 1.71 km/h - 26 km/h and a nominal rotational speed of the electric motor of 2350 s^{-1}.

An agricultural electric tractor performs intense and complex tasks during its lifetime, being challenging to quantify all the activities and the solutions designed to perform its specific purpose.

In evaluating electric tractors we had to split the total power output among different potential loads, such as wheel loads, hydraulic tools, mechanical tools, power take off, etc., activities that are also dependent on the agricultural processes that are carried out (ploughing, cultivation, sowing, roller packing, harrowing). In figure 2, one can observe the power needed for the operation of an agricultural tractor, depending on the main soil tillage performed, under external conditions close to optimal from which we can draw the conclusion that the most intense activity is represented by plowing (*Tong F., 2015*). Although there are many variables that could change the absolute power levels, it is observed that the percentage do not suffer significant changes.

Figure 1. INMA Bucharest electric tractor prototype

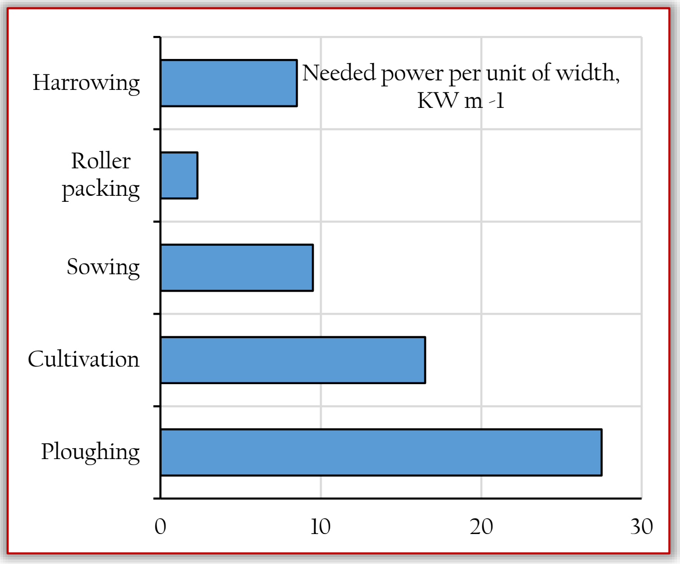

Figure 2. Electric tractor power needed for the main soil works, depending on the main soil tillage performed

RESULTS

The activities performed by the electric tractor were continuously monitored using a QuantumX 1615 amplifier data acquisition system to test the draft force, while a 10 kN hydraulic cylinder have been managed to measure in INMA Bucharest laboratory the strain gauges for the draft force.

Have been then calculated the drawbar power Pd and the electric power input Pe for the electric motor using the equations 1, 2, followed by the determination of power delivery efficiency of the system during plowing (PDE) equation 3. The drawbar power Pd (W), have been calculated as the as the product between mean draft force Fd (W) and actual working speed va (m/s).

$$Pd=Fd va,\ [W] \quad (1)$$

Electric power input has been calculated as product between battery voltage U, (W) and battery current I, (A), as follows:

$$Pe=UI,\ [W] \quad (2)$$

$$PDE = Pd/PE \quad (3)$$

The plowing process was performed at 3 depths (0.1 m; 0.15 m and 0.2 m), the results of the activity of the electric tractor during the plowing process are being presented in Table 1.

Table 1. INMA Prototype electric tractor testing

No.	Working depth a, m	Actual working speed va, m/s	Mean draft force Fd, N	Drawbar power Pd, W	Electric power input Pe, Kw
1	0.1	0.50545	3822	1932	3
2	0.15	0.48895	5728	2801	5
3	0.2	0.4719	7527	3552	7
4	0.1	0.9988	3884	3879	8
5	0.15	0.9526	5801	5526	10
6	0.2	0.8954	7644	7013	13
7	0.1	1.4032	3926	5509	11
8	0.15	1.3392	5844	7826	14
9	0.2	1.2608	7789	9571	19

No.	Power delivery efficiency PDE	Tractor autonomy, h	Ploughing productivity, ha/h	Total ploughed surface, ha
1	0.55930	5.00	0.09	0.46
2	0.60964	3.76	0.09	0.33
3	0.48300	2.35	0.08	0.20
4	0.48858	2.18	0.18	0.39
5	0.56958	1.78	0.17	0.31
6	0.55647	1.37	0.17	0.23
7	0.47958	1.50	0.25	0.38
8	0.54217	1.20	0.24	0.29
9	0.49988	0.90	0.22	0.20

Unlike electric road vehicles, that are usually charged using local grid, off-road electric equipment needs more flexibility by adopting dedicated solar PV charging systems located closer to the working area.

In evaluating the feasibility of implementing a photovoltaic power supply system for powering off-road electric tractors, models have to be created to determine the relations of the electricity balance, financial consequences, CO_2 emissions reductions, or grid interactions.

In countries that have increased irradiations levels all year long, the solar photovoltaic charged electric vehicles can be operated more effectively than in countries with a high variability of irradiation over the year.

The potential to produce electricity using energy generated by the Sun is complex and depends on variable factors.

An important aspect to be considered is the region characteristics when calculating the production capacity, taking into account the month in the year, when the specific agricultural activity takes place.

The measurement of average daily solar radiation that can be converted into energy is called Solar insolation and express the average daily kilowatt hours received per square meter in a day.

Insolation intensity levels on the globe have been measured, so that the annual estimations can be made by modeling the average data from the last 10 years, and then validate the future estimations using a pyranometer and a photovoltaic panel. Corrections are needed, given the discrepancies generated by climate change, shading areas or various other losses.

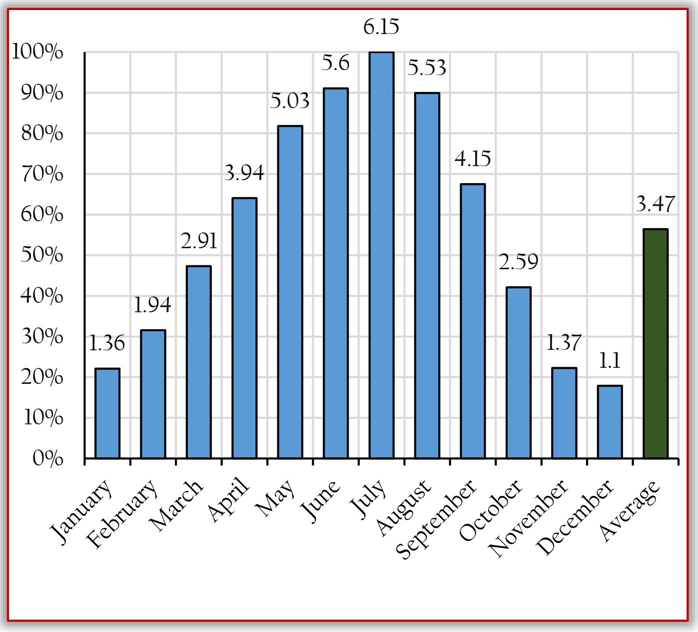

Figure 3. Insolation average levels in Bucharest using last 10 years estimations, in KWh/m2 per day, values that were validated using a pyranometer and a photovoltaic panel

Figure 3 shows that the months in which the activity of agricultural works is maximum coincides with the period in which the insolation in Romania is at high average levels. The chart also offers the possibility for the management to change the planning of some activities, which can be done in a longer margin of time, so as to benefit from the maximum potential generated by the panels.

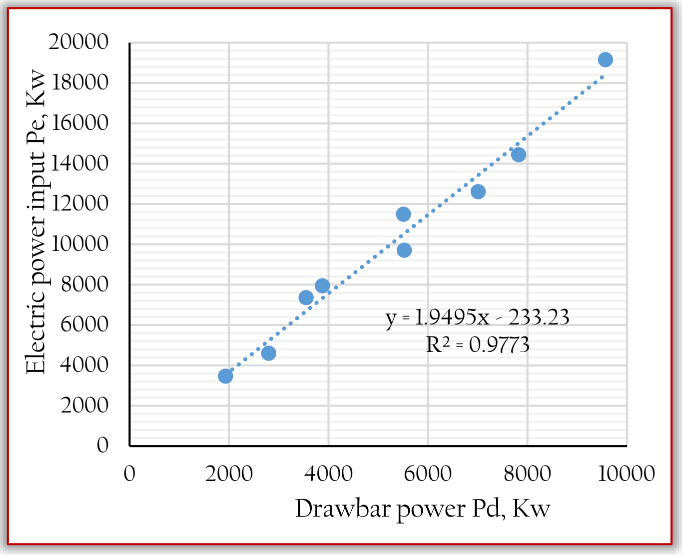

Figure 4. The determined electrical power

By interpolating the monitored values of drawbar power Pd, and Electric power input Pe, we can determine a dependency relationship between the two (Figure 4). This might be an important variable to determine electrical power, when knowing the drawbar power.

In order to estimate the energy required to perform various works with electric tractor prototype, we have used equation 4. The needed energy E (Kwh) represents the number of hours in which the tractor consumes that electric power. The energy generated in output of a photovoltaic system is dependent by a solar panel area (A, m^2), a solar panel yield (r, %), annual average irradiation on tilted panels (H, kWh/m2.y), and performance ratio (PR, %). The performance ratio is a coefficient for losses that can occur such as: inverter losses, temperature losses, DC cables losses, AC cables losses, shadings losses, losses at weak radiation, losses due to dust, snow, etc.

$$E = A * r * H * PR, [Wh] \qquad (4)$$

The energy required for the operation of an electric tractor varies greatly depending on the activity to be performed, some activities such as plowing requiring high power to operate, while some other activities such as spraying crops are not so demanding on energy requirements. The sizing of the photovoltaic power supply system must be made according to the activities to be performed with the electric tractor.

Considering that annual irradiation is dependent on the month of the year, with values between 496 kWh/m^2_year and 2245 kWh/m^2_year, a solar panel yield of 15%, a performance ratio of 0.73 and the total losses of 15 % with the site, technology, temperature, dust, etc., the photovoltaic panels areas variation depending on the produced energy can be seen in figure 5. Have been considered losses caused by temperature, above average (10%) because it is assumed that the power plant will be positioned close to the agricultural land where temperatures are very high.

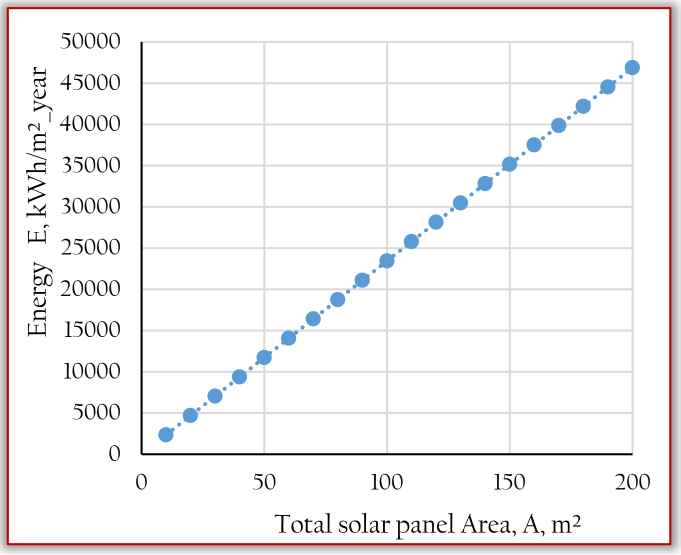

Figure 5. - The variation of the photovoltaic panels areas depending on the average produced energy

However, the graph might not be relevant enough, considering that the insolation is dependent on the seasons and the month of the year.

Therefore, have been calculated the variation of the areas needed to be covered by photovoltaic panels, depending on each month of the year and the annual average irradiation, (figure 6), which can be very important in the design of photovoltaic installations for powering electric tractors working off-road.

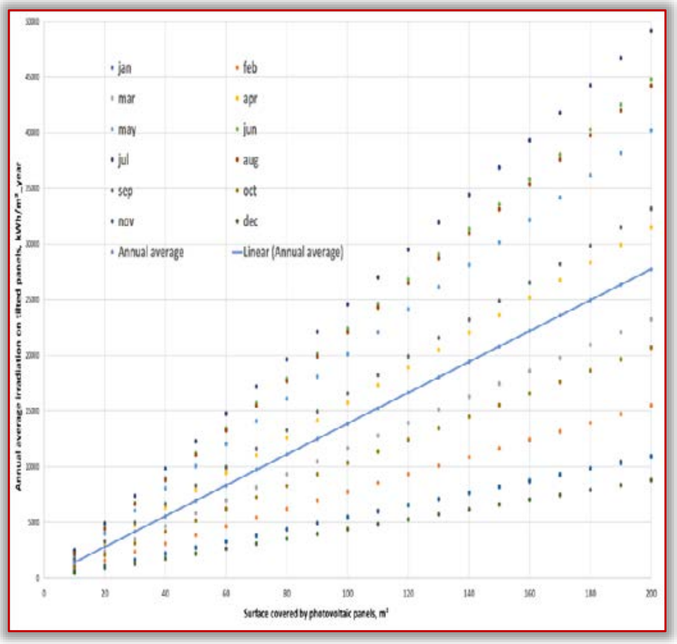

Figure 6. Variation of the total area needed to be covered by photovoltaic panels, depending on each month of the year and the annual average irradiation

CONCLUSIONS

In order to calculate the power needed of an electric tractor designed for off-road works we have been testing an experimental prototype, designed by INMA Bucharest, in different working conditions. The potential of photovoltaic energy production in Romania was then analyzed using both statistical data and corrections by monitoring with a pyranometer.

The results were then used for analysis the variation of the total area needed to be covered by photovoltaic panels, depending on each month of the year and the annual average irradiation, useful element in evaluating the usefulness of installing an autonomous photovoltaic system, for powering tractors with off-road use.

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Note:

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