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A Literature Review on the Electric Tractors and Assessment of Using for Türkiye

Elektrikli Traktörler Üzerine Literatür Taraması ve Türkiye'deki Kullanımına Dair Değerlendirilme

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ABSTRACT

Recently, an increase in electrification has been observed in the automotive sector.. Original Equipment Manufacturers (OEMs) state that they will cease production of internal combustion engine technology. In particular, with the rapid change in technology from internal combustion engine powertrain systems to electric powertrain systems, they also ended their investments and R&D studies in this field.Hybrid, battery and fuel cell electric vehicles are main alternative solutions for the powertrain systems.

Tractors are considered as off-road vehicles and need special auxiliary systems suitable for field use. Electrical systems have been used for a while in these auxiliary systems (PTO, hydraulics, pumps, fans, air conditioning system and etc.). On the other hand, the electrification of the drive system and power transmission mechanisms in tractors is still in its infancy. The main reason for this is the working conditions of tractors used for agricultural purposes.

Sustainable agricultural activities can only be possible with the right approaches. In this context, tractors are the fundamental equipment that affects the yield and quality of the agricultural products and has a very important contribution to the use of work and time.

In this study, a literature review was made on electric tractors. For the conditions of use, an approach was taken from the perspective of a case study and a cost-benefit analysis of its usability was carried out by comparisons with commonly used diesel tractors. Finally, in line with the data obtained, evaluations on the use and spread of electric tractors in Türkiye were presented.

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ÖZET

Otomotiv endüstrisinde içten yanmalı motorlu tahrik sistemlerinden, elektrik motorlu tahrik sistemlere doğru genel bir eksen kayması söz konusudur. Bu doğrultuda hibrit, tamamen elektrikli ve yakıt hücreli sistem çözümleri kullanılan alternatifler arasında yer almaktadır. Traktörler gibi arazi kullanımına uygun taşıtlarda ise, yardımcı sistemlerde (hidrolikler, pompalar, fanlar ve klima sistemi vb.) elektrikli çözümler kullanımda olmasına rağmen, tahrik sisteminde ve güç aktarım mekanizmalarında elektrifikasyonun henüz başlangıç aşamasında olduğu görülmektedir. Bunda tarımsal amaçlı kullanılan traktörler ile otomobillerin arasında çalışma koşulları açısından yer alan farklılıkların etkisi çok büyüktür.

Sürdürülebilir tarımsal faaliyetler, ancak bu alanda kullanılan doğru yaklaşımlarla mümkün kılınabilir. Bu kapsamda tarımsal alanda ürün verimine, kalitesine etkiyen; iş ve zaman kullanımında çok önemli katkısı olan temel ekipman traktörlerdir. Tarımsal uygulamalarda kullanılan traktörlerin yüksek yaş ortalamasına sahip olması verimlilik açısından çok önemli bir dezavantajı beraberinde getirmektedir. Ekonomik ömrünü fazlasıyla doldurmuş traktörlerle yürütülen tarımsal faaliyetlerde yakıt ve yağ tüketimlerinin yansıra bakım & onarım maliyetlerinde de büyük oranda artmaktadır. Bu durum tarımsal kalkınma kapsamında sağlanan desteklerin de etkin kullanımına engel teşkil etmektedir.

Bu çalışmada elektrikli traktörler hakkında literatür taraması yapılmış, kullanım koşulları için örnek bir vaka çalışması üzerinden sunulan yaklaşım doğrultusunda kullanılabilirliği değerlendirilmiş ve maliyet-fayda analizleri yaygın olarak kullanılan dizel traktörler ile karşılaştırılarak yapılmıştır. Son olarak elde edilen veriler doğrultusunda Türkiye'de elektrikli traktörlerin kullanımı ve yaygınlaşmasına ilişkin değerlendirmeler sunulmuştur.

1. INTRODUCTION

According to 2019 data, there are approximately 2 Million tractors in Türkiye (Anonymous, 2020a). In this context, the number of double axel tractors with 25 Hp and 25 Hp + (more than 25 Hp) used in agricultural applications which are 1.248.011 units and their average age is 25,3.

In the present case, the high average age of the tractors used in agricultural applications brings with it a very important disadvantage in terms of productivity. Meanwhile, high amounts of fuel and oil consumption occur in agricultural activities carried out with tractors that have already reached their economic useful life. In addition, there is a significant increase in maintenance & repairmen costs. Therefore, aging prevents the effective use of state subsidies and supports provided within the scope of agricultural development. Moreover, with reference to the relevant data, the average age is 40+ among approximately 650.000 tractors that are actively used in agricultural activities in Türkiye (Anonymous, 2020 a; Anonymous,2020 b).

The useful life of tractors used for agricultural purposes is between 10.000 to 12.000 hours according to international standards. In Türkiye, there are previous studies carried out for tractors. According to this framework, references takes from the records of the authorized tractor services; the average annual usage period for –19.396 tractor samples in total - was indicated as 443 hours. It is foreseen approximately from 20 to 24-year lifetime for the tractors used for agricultural activities in Türkiye (Evcim and Özgünaltay Ertuğrul, 2017). In the light of the forecasts and available data, it can be said that a very important part of the tractors (more than 50%) used for agricultural purposes in Türkiye have completed their economic usable life.

Although, they completed their economic life, agricultural tractors cause losses in many ways. Some researches carried out in this context, tractors that have completed their economic life, cause an increase in fuel consumption of 700 liters per year and a loss of 150 hours of work because of malfunctions. Also, exhaust emission measurements were made with tractors of 56 different brands and models which were age of 25 + and1,816 kg CO_2e for 250 hours/year operating time (Evcim and Ulusoy, 2006).

According to Turkish Association of Agricultural Machinery Manufacturers (TARMAKBIR) data, the total number of tractors produced by years in Türkiye by Başak, Erkunt, Hattat, Tümosan and Turktraktor is given in Figure 1 (Anonymous, 2020 a).

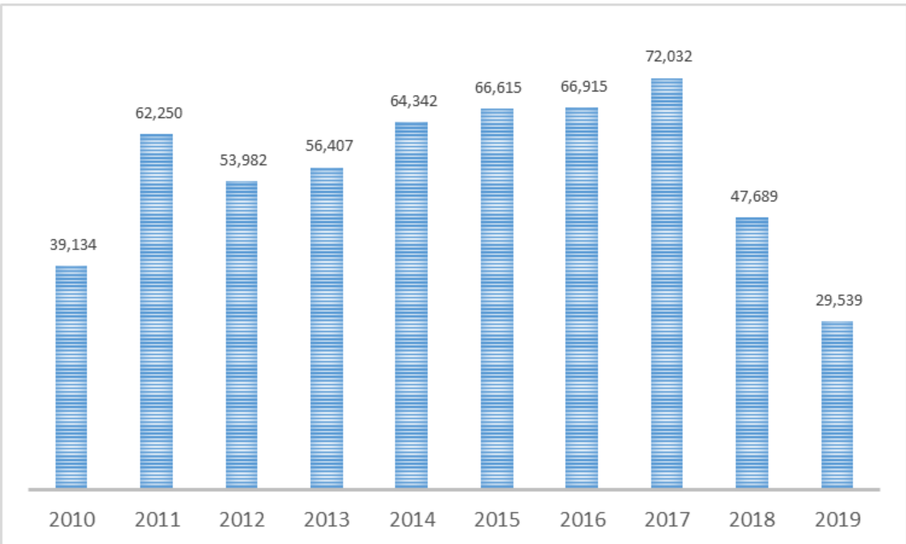

Figure 1. Tractor production data by years in Türkiye

Moreover, the average number of imported tractors was reported as 16.75% in Türkiye. The distribution of the tractors sold according to the average powertrain is also given in Figure 2.

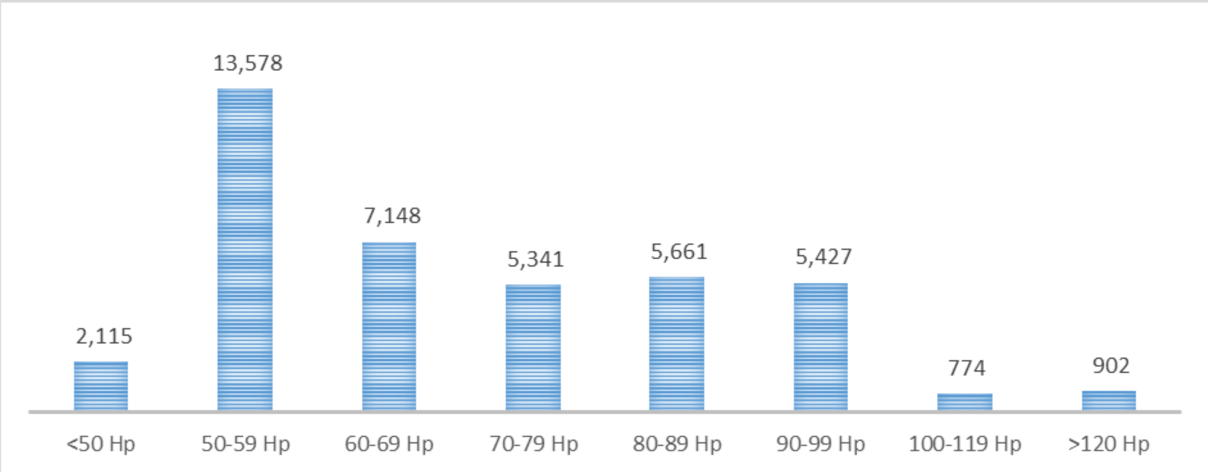

Figure 2. The distribution of the tractors sold according to the average powertrain

The important system solutions on electric propulsion systems are available in cars, buses, trucks and also in off-road use like in underground mining vehicles. Although in the automotive industry with different concepts or construction equipment have electrical powertrain concept solutions, it is noteworthy that the tractors with electric powertrain which are used for agricultural applications remain only at the prototype stage.

The basic approach for the transition from internal combustion engines to electric motors in propulsion systems is not different in the vehicle concepts on road or off-road use. Similar system solutions are offered, depending on power requirements. For the tractors, it is considered that the transition to electrical drive systems cannot go beyond concept design and proto-type applications, especially due to cost and capacity limits based on usage conditions.

The key component for the tractor structures is the internal combustion drive engine that provides the main power generation. In tractors, power flow is provided from the main drive engine to the wheels through the transmission and to the PTO and hydraulic systems with mechanical gear in power transmission structures. In system solutions where belt / pulley structures are also used, the power flow to all auxiliary systems is transmitted through the internal combustion engine. Transition to electrical system solutions for some or all of these components for tractor concepts is listed topologically in Figure 3 (AVL, Concept).

As in all other automotive industry, the internal combustion engine is protected in hybrid tractor topologies; electrical components for drive and auxiliary systems are included in the system to ensure efficiency. Hybrid tractor structures have been introduced as a priority transition concept due to range limitations compared to fully electric tractors, as well as battery dimensions, weight, and costs. However, in commercial terms, it is seen that both the production portfolio and the sales numbers do not have the expected impact across the world.

Figure 3. Electric tractor system topologies

In an internal combustion engine tractor, hydraulic and coolant pumps, air brake and air conditioning compressors, radiator fan are considered as auxiliary systems which are driven by the main drive engine. Performances of auxiliary systems are dependent on the speed of the main drive motor. In this sense, in order to keep any system active, the main drive engine must work and possible efficiency losses come to the fore in line with the capacity used according to the operating conditions. Electric and hybrid concepts are advantageous in tractors as well as in other automotive structures. The separation of the auxiliary systems and the provision of an external electrical drive allows to operate more efficiently while reducing the required main drive motor capacity and size.

The auxiliary systems that require great power for electric tractors are especially PTO and hydraulic systems. The system designs for the relevant powertrains are important. Thanks to the control methods specific to electric motors, it stands out as new functions and additional safety-enhancing elements introduced to electric tractors. For example, through the torque detection feature, a possible jamming can be detected in the grinder connected to the tractor PTO and the speed can be reduced and automatically reversed to eliminate the jamming.

Looking at modern agricultural practices in large-scale farms around the world, innovative approaches integrated with autonomous tractors draw attention. Electric tractors contain the infrastructure that will provide fast adaptation structurally for autonomous driving systems as in other automotive applications. While electric tractors provide advantages thanks to their low energy consumption and maintenance & repair costs; they also offer a zero-emission concept by operating with renewable energy options. Using of electric motors in the main drive system provides an advantage for the high torque requirement needed in agricultural applications, it offers a comfortable driving and improved safety equipment.

Nevertheless, the main difficulties regarding electric tractors to be used in agricultural applications are the lack of necessary energy infrastructure for charging in usage areas (agricultural areas), having difficult working conditions, limitations regarding battery technology and most importantly, high initial purchase cost. Especially in agricultural applications, the working environment where the tractors are located is very dusty and has an extremely hot and high humidity level for during the summer months when agricultural activities are carried out (such as Çukurova in Adana). For this reason, durable and reliable power electronics-components and, effective and sufficient cooling infrastructure are essential for the electric motors and battery packs. In addition, the thermal control structures to be established for the specified operating conditions should be considered as an additional factor that increases the battery energy consumption.

As with other electric vehicle concepts, battery efficiency is very important for electric tractors. Sufficient power and energy density has not yet been achieved in current battery technologies to compete with conventional tractors based on internal combustion engines for agricultural applications. Increasing the battery size in line with the requirements causes high costs and increased weight for electric tractors (this also reduces the overall efficiency of the tractor).

2. STUDIES ON ELECTRIC TRACTORS

In the study conducted by Troncon et al. (2019), a feasibility study was prepared on working conditions and energy consumption for a tractor used in agricultural applications to be electrical (Troncon et al., 2019).

It was stated by Ueka et al. (2013) in Japan that a tractor with internal combustion engine was retrofitted as an electric tractor in order to reduce environmental impacts in agricultural production and the total vehicle weight increased and the center of gravity changed. According to the diesel tractor, 70% of the energy required for soil cultivation and driving, 1300 m^2 area can be cultivated with 1 full charge (it is stated that the plowing is done at 0.3 $m\ s^{-1}$ speed and 10 cm depth). Finally, approximately 70% reduction of CO_2 emission was achieved (Ueka et al., 2013) .

According to the simulation modeled on Matlab for the dual motor drive system for electric tractors by Chen et al. (2019), optimization for the essential parameters of the drive system as engine power, battery capacity, number of gears, etc. is presented.

Retrofit from a diesel tractor with 20 kW engine power to a fully electric tractor was realized by Arjharn et al. (2001) energy consumption characteristics and agricultural application performance have been evaluated.

Ghobadpour et al., (2019) are stated that tractors are generally suitable to work for high loads and low speeds. Also, other systems like PTO and hydraulic systems are defined as elements requiring extra power to tractors. On the other hand, it has been stated that energy supply increases agricultural costs, as agricultural tractors generally operate away from the electricity grid and fuel stations. With the approach put forward, the use of a hybrid electric tractor concept consisting of renewable energy sources and biodiesel engine in agricultural applications was taken into consideration and an alternative approach was presented that allows farmers to meet the energy demand required or to provide energy to the local electricity grid (Ghobadpour et al., 2019).

For agricultural applications, while Xu et al. (2014) designed a prototype electric tractor with centralized motor system architecture; Gao et al. (2009) approach based on the serial hybrid electric tractor system architecture.

Zhang et al. (2016) developed a dynamic algorithm to minimize energy loss and provide optimum control for the electric tractor concept by modeled with two drive motors, gear system and clutch structure. According to the simulation results obtained, the energy loss of the new two-coupling topology compared to the original design is 12.4%; Similarly, it has been revealed that the optimum system design can reduce the energy loss by 3.36% compared to the original design.

Modeling and simulation study results of an electric tractor with plug-in hybrid drive system that enables the use of biodiesel fuel with the PV powered battery pack developed by Ghobadpour et al. (2020). According to the results obtained, the hybrid-electric propulsion system provided with 4.4kW Bio-Gen for a 2100 kg electric tractor can not provide similar performance with the conventional drive system tractor with an internal combustion engine of the same quality.

In the thesis prepared by Savaşır (2013); The performance values of a 55 hp internal combustion engine tractor based on different operating conditions have been calculated. To meet the demands obtained regarding this, the suitable electric tractor concept has been modeled. As a result, he stated that the electric tractor concept was not suitable for use, considering the price conditions of the existing diesel tractors in the market and the prediction that the battery capacity could not meet the needs in the field.

AVL works on a different electric tractor concept, unlike the studies based on the standard designs of internal combustion engine tractors on the market. In the article prepared in this context, functional limits, weight distribution imbalance or not providing enough space for the battery, etc. It is pointed out that conditions will necessitate different approaches for existing electric tractor concepts in the long run (AVL Solution Sheet).

A recent study on the physical dimensions, requirements and performance results of the hybrid tractor used for vineyard and garden applications stated that unlike normal automotive concepts, hydraulic and PTO systems in tractors complicate the envisaged electric tractor concept structure (Troncon and Alberti, 2020).

It was stated by Yoo et al. (2013); the system architecture of electric tractor design based on Carsim and ASM (Simulink based) is based on a 2-motor structure, separate for drive and auxiliary systems. It has been reported that the exchange of electrical drive components will be compatible with the internal combustion engine systems currently used

In another study on the use of electric tractors in India, it was reported that the key elements such as high torque, low maintenance, low operating costs and zero emissions are strong factors for the adoption of electric tractor for the agricultural sector where 55% of the population makes a living. In contrast, the very high ini-tial cost of purchasing electric tractors, the lack of energy infrastructure for charging, and the lack of awareness of emission emissions were considered as major weaknesses (Malik and Kohli, 2020).

Magalhaes et al. (2017) drew attention to the negative impact of ambient conditions in his study, which addressed the practical problems in the field of electric tractors.

Also, Caban et al. (2018) analyzed the market potential of electric tractors in Poland through a survey they conducted; similarly, they concluded that switching to electric drives in tractors had some difficulties (Caban vd., 2018).

Frederickson et al. (2022) collect and analyze activity data from diesel engine tractor and they us efor zero emission electric yard tractor. The performance of the vehicle/equipment was analyzed in terms of the state of charge (SOC) and fuel/energy consumption per day and energy consumption per work completed/distance driven. The data was analyzed to determine performance activity patterns including hours of operation and miles traveled per day.

Chenet al. (2022) stated that the electrical tractor is bound to become a future agriculte trends. Their study is related to design and implement a lightweight, energy-saving, and less polluting electric tractor, which corresponded the requirements smallholder farmers.

3. ELECTRIC TRACTORS IN THE WORLD

The general opinion in the academic studies mentioned above; despite the advantages of electric tractors, the desired results cannot be achieved due to structural and cost factors. It is seen that generally limited to studies on small scale and prototype applications. On the other hand, the world's leading tractor manufacturers also have electric tractors for those that are sold commercially or are still at the concept or prototype stage. So, it is expected to enter the agricultural machinery market in the next few years.

The detailed technical specifications of electric tractors around the world are shown in Table 1. Among the available information, it is possible to express different values, especially in terms of charging and operating times, by considering the infrastructure and operating conditions.

Table 1 Electric tractors in the world and their technical specification

Brand/ Model	***Model***	***Power Capacity***	***Battery Capacity***	***Operation Time*** [1]	***Made in***
Fendt / e100 Vario		*50 kW*	*100 kWh*	*5 h*	*Germany*
John Deere / Sesam		*150 kW*	*130 kWh*	*3 h*	*USA*
Escort/ Farmtrac 26E		*19 kW*	*21 kWh*	*6 h*	*India*
Rigitrac / SKE 50		*50 kW*	*80 kWh*	*5 h*	*Switzerland*
ZY Electric		*75 kW*	*95 kWh*	*5 h*	*Türkiye*
AVL (consept)		*50 kW*	*140 kWh*	*NA*	*NA*

In the market analysis conducted in electric tractor sector, the German tractor manufacturer Fendt stands out for the first time. The produced e100 Vario model has a motor power of 50 kW and a Li-ion battery capacity of 100 kWh. It is a 100% electric tractor and has been put on the market for sale. It is stated that the company provides 5-hour uninterrupted working opportunity under real field conditions with the model foreseen for agricultural applications such as vineyards and gardens (Fendt e100-vario).

American tractor manufacturer John Deere produced the electric tractor as a prototype which called the Sesam model in 2016. It can provide a total of 300 kW of power from a 150 kW electric motor for each axle, powered by a 130 kWh Li-ion battery pack. The tractor is the largest power capacity electric tractor in this class (John Deere Sesam).

Indian tractor manufacturer Escorts launched the electric tractor model Farmtrac 26E, which also targets the market for small-scale vineyard and orchard agriculture ap-plications. The model has the

[1] It is expected to vary depending on the agricultural practice and field conditions.

opportunity to work for approximately 6 hours with a 19 kW electric motor and 21 kWh Li-ion battery pack (Escorts Farmtrac).

The Swiss tractor manufacturer Rigitrac is also among the companies that produce electric tractors. In the system architecture of the electric tractor revealed, there are 4 electric motors in total, 1 for the front axle, 1 for the rear axle and 1 for the PTOs (front and rear). Rigitrac SKE 50 model is designed for garden applications with 80 kWh Li-ion battery capacity and 50 kW motor power (Breen, 2019).

The last player of the electric tractor sector is from Türkiye. Türkiye's electric tractor brand ZY Electric. This electric tractor project is belong to General Directorate of Agricultural Research and Policy, subordinate to the Ministry of Agriculture and Forestry. Within the scope of the project, a joint venture was established between Ziraat Private Equity Investment Trust Inc. (Ziraat GSYO) and Trev Energy Otomotive Inc. It has been reported that mass production will begin in the recently established factory. Within the scope of the project 2 different models were prototyped. It was launched last year. It is stated that the first prototype has a power of 75 kW (105 hp) and a battery capacity of 95 kWh (ZY Electric).

4. ELECTRIC TRACTORS IN TÜRKİYE

In this paper an overall assessment is made by considering the electrical tractor design concepts put forward in the world which based on agricultural activities in Türkiye. In this respect, a design input has been created for electric tractors according to the results of the research conducted in Adana, which is one of the leading agricultural regions of Türkiye.

Also, in the analyzes carried out, the approach is presented based on the Türkiye's electric tractor brand ZY Electric. It is stated that the first prototype has a power of 130 Hp (96 kW) and a battery capacity of 95 kWh. Detailed technical information on the first electric tractor prototype is given in Table 2 (ZY Elektrikli).

Table 2. Technical specifications of Türkiye’s first electric tractor

<table>
<tr><td>Traction Drive Power</td><td>130 Hp</td><td rowspan="4">318 HP</td></tr>
<tr><td>PTO Drive Power</td><td>160 Hp</td></tr>
<tr><td>Hydraulic Systems</td><td>20 Hp</td></tr>
<tr><td>Other Auxiliary Systems</td><td>8 Hp</td></tr>
<tr><td>Battery Capacity</td><td colspan="2">95 kWh</td></tr>
</table>

Accordingly, in the summer working conditions, where agricultural activities are concentrated, the actual operating conditions carried out by tractors are taken as reference. Due to the extremely hot weather conditions in the summer months, the main approach is the plowing operation, which is the most challenging activity for agricultural applications carried out in 2 stages, usually between 06: 00-11: 00 in the morning and 16: 00-24: 00 in the afternoon. In this scale, with a single tractor and a single driver, a maximum of 45-50 decares of fields can be plowed within a total of 12-13 hours per day.

$$ET = (GM \times \eta \times t) \tag{1}$$

ET : Energy consumption of tractors, (kWh)
GM : Electric motor power, (kW)
η : Load capacity, (%)
t : Is the time, (h)

$$P = (BC \div ET) \tag{2}$$

P : One-charge-use of tractor,
BC : Total battery capacity, (kWh)
ET : Energy consumption of tractors, (kWh)

$$CT = (BC \div GC) \tag{3}$$

CT : Charging time of tractor, (h)
BC : Total battery capacity, (kWh)
GC : Charge capacity of charge station, (kW)

Considering these data; the first approach for the Sesam Electric Tractor model designed by John Deere is presented. The total power requirement of this tractor, including drive and PTO, is 400 hp. The battery usage capacity foreseen for 12-hour uninterrupted operating conditions, based on 50% load conditions, corresponds to 2.280 kWh for full charge in one time. This capacity value for the battery corresponds to a volume of approximately 5000 lt and a weight of 15 tons based on the Li-ion structure (Peter, 2019).

The other references approach is the 80 hp tractor concept of the Fendt e100 Vario. The capacity of the 100 kWh battery (Li-ion structure) in the tractor corresponds to its weight of approximately 600 kg. Similarly, with Sesam, when using 50% load capacity, operating conditions that require recharging after 4 hours (Peter, 2019).

Finally, similar predictions made by ZY Electric. In this context, a projection was made for a capacity of 318 Hp based on the prototype design reported for ZY Electric. In the specified capacity use, it is evaluated that the power requirement can be used for a maximum of 1 hour with a battery capacity of 95 kWh for operating conditions based on the use of 50% capacity as in other approaches. On the other hand, it is seen that approximately 480-600 kWh of battery capacity is required at 50% full capacity and 4-5 hours of uninterrupted use. For an electric tractor of this scale, it must have a charging station capacity of at least 120 kW and sufficient energy infrastructure to charge the battery capacity in 5-6 hours.

5. CONCLUSION

In terms of system architecture, traditional approaches based on existing tractor with internal combustion engine models are seen to be gaining weight in electric tractor concepts that have been introduced around the world. Basically, the system architecture is built with a battery pack instead of just the diesel engine and related components, a central electric motor (concepts offering different approaches are also possible) and related power electronics (converter) structures.. In this configuration, the electric motor is directly coupled with the regular gear diesel engine with the integrated gear. On the other hand, it is seen that belt / pulley applications based on traditional approaches or system solutions with external drive are used for auxiliary systems. For PTO systems, an external drive system is preferred in all electric tractor concept approaches. Due to current conditions regarding electric tractors and limitations in battery technology, it is considered to be optimum for agricultural applications with small capacity tractors. However, for electric tractors, most of which are in the concept or prototype stage, innovations that will be introduced with different approaches from traditional system designs are expected to come to the fore in the near future. Especially when agricultural operating conditions are taken as a reference, it is essential to put forward sufficient and sustainable charging systems and energy infrastructure solutions for electric tractors corresponding to diesel tractors. In cases, high battery capacities, associated costs and therefore additional weights are among the most important difficulties for electric tractors where these requirements cannot be met that is why it makes it difficult to compete under the current conditions. Innovative approaches based on total cost of ownership should be introduced in line with field analyses to be carried out with effective and efficient system solutions. Financial support to be offered to farmers, incentives to be provided under the condition of using electric tractors or additional agricultural support packages, etc. may be necessary and awareness also be raised for electric tractors through sustainable agricultural subsidies.

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