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Study of the Efficiency of Using Facilities Based on Renewable Energy Sources for Charging Electric Vehicles in Kazakhstan

Sayat Shaimurunov[1], Kuanysh Ryspayev[1*], Arman Ismailov[2], Azamat Zhikeyev[3], Bulat Salykov[4]

[1] Department of Mechanical Engineering, Engineering and Technical Institute named after A. Aitmukhambetov, A. Baitursynov Kostanay Regional University, Kostanay 110007, Republic of Kazakhstan
[2] Department of Software, Engineering and Technical Institute named after A. Aitmukhambetov, A. Baitursynov Kostanay Regional University, Kostanay 110007, Republic of Kazakhstan
[3] Institute of Distance Learning and Additional Education, A. Baitursynov Kostanay Regional University, Kostanay 110007, Republic of Kazakhstan
[4] Department of Machines, Tractors and Automobiles, Engineering and Technical Institute named after A. Aitmukhambetov, A. Baitursynov Kostanay Regional University, Kostanay 110007, Republic of Kazakhstan

Corresponding Author Email: ryspayevkuanysh@gmail.com

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ABSTRACT

In this study, the process of popularisation of electric vehicles in Kazakhstan is considered in more detail, since there is a small number of these transports, which negatively affects the economy and ecology of the country. The purpose of this study is to investigate the efficiency of the use of electric vehicles and the use of facilities based on renewable energy sources for charging them on the territory of Kazakhstan. The research methodology is the analysis of literature sources to investigate the efficiency of the use of electric vehicles, the correct development of models for the location of charging stations, and the efficiency of renewable energy sources as a way to boost the economy and reduce energy costs. The ways of popularising electric vehicles in the country were considered. The modelling of charging stations for electric vehicles was studied. In addition, the electric vehicle batteries were investigated. This study can be used to support decision-making for the design of charging stations for electric vehicles in the cities of Kazakhstan, which would bring economic and environmental benefits.

1. INTRODUCTION

Currently, there is a huge demand for environmentally friendly and energy-efficient transport. This type can be attributed to electric vehicles that have reached the first positions on the world market in recent years. In Kazakhstan, the use of this category of cars is just emerging, and according to EnergyProm, there were 528 electric vehicles in the country in 2021 [1]. By 2020, the share of renewable energy in Kazakhstan has reached the planned target of 3%, in this regard, 15% is expected to be achieved by 2030 [2]. Renewable energy sources are an efficient alternative to fossil fuels. The use of all types of fuel harms the environment because carbon is released, which results in an increase in air temperature, i.e., leads to global warming, causing droughts and crop losses in Kazakhstan. In this regard, the Kazakhstan 2050 Strategy proposed by the former president is an impetus for increasing the share of renewable energy sources and for the introduction of infrastructures that would favourably affect all areas of human activity. However, a survey was conducted among the population of the country, and conclusions were drawn that people avoid renewable energy sources, citing financial and technical difficulties (the high cost of acquisition, the growth of electricity prices, insufficient number of charging stations, maintenance of the battery, doubts about the operation) [3, 4].

Transport is responsible for most of the emissions of CO_2 into the environment. Therefore, the transition from cars with an internal combustion engine to electric vehicles is an important step towards a green economy [5-7]. Currently, there are two types of electric vehicles – plug-in and battery-powered. An electric vehicle charged with renewable energy sources is more environmentally friendly than other types of vehicles. In addition, renewable energy charging stations are equipped with energy saving storage systems so that the stored energy can be used during the absence of a primary source. Commonly, the storage system is based on batteries, hydrogen, or other technologies. It is worth considering that renewable energy sources have achieved rapid technological growth in recent decades. For the design and development of charging stations, factors such as charger capacity, location, etc. are paid attention to. The amount of energy generated by the charging station depends on the economic and technical conditions of the entire system.

There are important categories of doubts when buying electric cars. These include an insufficient number of charging stations and electricity costs. These factors arise mainly because the popularity of purchasing electric vehicles in Kazakhstan is just beginning to gain momentum. According to open data, only 103 charging stations for electric vehicles were equipped in Kazakhstan in 2020 (51 in Nur-Sultan and 52 in Almaty) [8]. Thus, it does not make sense for residents of other

regions of Kazakhstan to purchase eco-transport, a small number of charging stations and their absence in other areas are an essential problem. Consequently, the problem of maintenance and repair follows, because the working staff does not have the skills to service electric vehicles.

In this regard, this study is relevant and innovative, because the solution of this problem would contribute to an increase in the number of users of electric vehicles, positively impacting the ecology of the country. This study analysed examples of the use of electric vehicles for the comparison. So, the purpose of study is to investigate the efficiency of the use of electric vehicles and the use of facilities based on renewable energy sources for charging them on the territory of Kazakhstan. The "Results and Discussion" section was divided into three parts, which discuss the three most important problems within this study. To begin with, the reason for the introduction of charging stations to attract potential buyers of electric vehicles was considered. Moreover, in this section, the reason for the use of renewable energy sources is investigated. The second question concerned the modelling of charging stations for power plants, considering studies in which renewable energy sources were used in the design (more often solar, and wind energy). In addition, solar energy is rapidly developing in Kazakhstan, for example, in the country, there is a cluster for the production of photovoltaic converters, the production of which starts from the extraction of quartz to the assembly of photovoltaic cells. The studies which propose a clear algorithm and software for the arrangement of charging stations were also considered. All the analysed studies can be applied anywhere in the world. In the third part, batteries and their disposal are investigated to present the advantages of electric vehicles to buyers.

2. MATERIALS AND METHODS

At the beginning of the 21st century, one of the main issues entered the world – global warming. Therefore, this study considered the advantages of electric vehicles. An electric vehicle can play a central role, if it is powered or charged based on renewable energy sources. The basis of the layout of charging stations for electric vehicles includes several stages – forecast of the need for charging electric vehicles, determination of the location of charging stations, modelling [9]. Studies in scientific journals from such collections as ScienceDirect, Nature Publishing Group, Taylor and Francis, Science, SpringerLink were analysed as research methods. The book "The Electric Car" was also analysed [10-13]. When entering the search, keywords such as the efficiency of electric vehicles, charging stations for electric vehicles, and hybrid charging stations were considered. The articles related to this study can be found in full using these keywords. When entering keywords related to this study into the search engine, a large number of results were noticed. Furthermore, the news portals of the Republic of Kazakhstan were used, which provide open sources and data on the number of electric vehicles for each year and the number and location of charging stations throughout the country.

Thus, the main task is to examine the development of a charging station based on renewable energy sources, in which an electric car could be charged during the day. There are currently 3 types of charging levels that have been standardised by electric vehicle manufacturers. As is known, level 1 charging does not require additional equipment, is intended mainly for home use, and takes from 8 to 16 hours. The second type of charging (level 2) is used in household and commercial charging stations. It takes from 4 to 8 hours to fully charge it. Level 3 charging is the most effective accelerated method (full charge time varies by about 20 minutes). For this study, level 2 is the most optimal, since it is compatible with all types of electric vehicles and plug-in electric hybrid vehicles in which level 1 charging is connected. That is, if solar cells are used as a renewable energy source, the model would include a station with an external battery, a solar panel. It is necessary to develop an algorithm in which the system would decide on the direction of the transfer of electricity between solar cells, batteries, electric vehicles, and the grid.

3. RESULTS AND DISCUSSION

3.1 Introduction and distribution of electric vehicles

According to open data sources, one of the leading projects of the United Nations Development Programme (UNDP) in Kazakhstan stated the discrepancy, exaggeration of the importance of current energy consumption standards in the cities of Kazakhstan on the international news portal KazInform [14]. Astana, Almaty, and Shymkent are considered the most economically developed cities in Kazakhstan. However, as mentioned above, owners of electric vehicles are located only in the capital and Almaty, i.e., in the southern part of the country, there are no owners of electric vehicles in the most profitable and hot areas of the county because there are no stations where the cars can be charged. Moreover, the users of such vehicles need to be sure that when travelling to a neighbouring city there would be an opportunity to charge their transport, otherwise, doubts related to psychological barriers, technological distrust, and safety and reliability problems cannot be overcome. The availability of fossil fuels is currently not sustainable, so the integration of electric vehicles and the expansion of renewable energy sources would extend the availability of oil for other more important areas. Thus, it is necessary to increase the number of and introduce charging stations to attract citizens to purchase electric vehicles, which would positively influence the economy and the natural climate of Kazakhstan. It would also have a positive impact on employment and development of the population, training and increase in the number of working car mechanics and the arrangement of electric car service centres in each city can influence the decision to purchase this type of car. In addition, the use of gasoline and diesel vehicles causes health problems such as anaemia, chronic bronchitis.

As is known, air pollution is a serious problem in Central Asia, which is proved by the fact that residents of Almaty often complain about smog. According to the open data of the Ministry of Ecology, Geology, and Natural Resources of the Republic (Republican State Enterprise "KazHydromet"), indications of exceeding the maximum permissible concentrations are often recorded, for example, for the period from February 8 to February 14, 2022, poor indicators were recorded in cities such as Astana, Almaty, Aktobe, Atyrau, Karaganda, Jezkazgan, Ust-Kamenogorsk, Pavlodar, Temirtau, Shymkent, Kyzylorda, Petropavl [15]. This information shows that Kazakhstan urgently needs the introduction and popularisation of the use of electric vehicles and renewable

energy sources. Residents of European cities face the same problems, however, to reduce CO_2 emissions, the authorities of Italy and Slovenia supported a project in which a survey was conducted among drivers about the advantages of electric vehicles compared to fuel-dependent cars [16].

There are cities in Kazakhstan with the authority to provide additional financing for the purchase or rental of electric vehicles [17]. For example, there are corporate fleets, and the state can influence owners to purchase electric vehicles. An incentive for citizens to buy electric vehicles may also be some privileges from the state, such as tax exemption, access to special purpose road lanes, exemption from parking charges or discount options. Thus, the government can influence the price decision of the operator and stimulate the charging load through financial subsidies. Since April 2019, the Italian government has introduced a subsidy for the purchase of electric vehicles (since August 2020, the subsidy has increased from 6000 euros to 8000), and Slovenia has introduced the same tactic [16].

Most drivers attach importance to free parking as a factor that would affect the purchase of electric vehicles. However, in the future, with the growth of the number of electric vehicles in the country, an increase in demand for electricity is possible, therefore, it is necessary to switch to a network with a system of renewable energy sources with extensive energy storage and its digital management. The technology should not only be adopted but also integrated into the knowledge of users. That is, an electric car should become part of everyday mobility models, which would make it relevant and in demand on the market. However, the authors analysed the replacement of all fuel transport with electric vehicles in Scotland [18]. The results show that the expanded use of eco-transports has a beneficial effect on the environment, but there are also disadvantages, which can be eliminated by using renewable energy sources in electricity production. The study also highlights the economic nuances for car owners – owners of electric vehicles spend more money compared to conventional cars with internal combustion engines, but in the future, users will save money due to lower electricity prices compared to gasoline or diesel fuel prices (savings of up to 69.1%). From the standpoint of innovation, an electric car is more than just a replacement for an internal combustion engine.

3.2 Modelling of charging stations for electric vehicles

The main task is to model a charging station based on renewable sources that would meet the requirements of an electric vehicle. Consequently, in the course of analysing the literature, three factors that play a role in the planning of charging stations were identified – electric vehicle charging demand, not uniformity in demand for charging power, and distribution network capacity. In turn, each factor is dependent on the other. Moreover, when developing charging stations, it is necessary to consider energy consumption at the moment and at the time of an increase in the number of electric vehicles in the country. If Kazakhstan 2050 Strategy is considered, the construction of charging stations based on renewable energy sources is the most effective, since such phenomena as an increase in energy consumption and the cost for it can play a negative role. Whereas solar and wind energy at such a time would have a priority in energy consumption in all areas of life. For example, for efficiency in the introduction of solar panels, the location and dimensions of the solar energy converter can be carried out using hybrid technology. This technology can reduce losses, voltage deviations, and the load reduction in the distribution network. The authors of Anand et al. [10] developed a model of a charging station charging from a hybrid energy source, namely from a solar photovoltaic cell, a battery, and a utility network. The model is suitable for this study because Kazakhstan has a good climate, in which solar cells are used, assembled by limited liability partnership "Astana Solar". This model demonstrated the ability to capture complex interactions between the energy resources present at the charging station in accordance with a predetermined operational strategy. The results of the study confirm the reliability and economic benefits of the production of photovoltaic energy and the storage of batteries. In the course of the study, reliability analysis, economic assessment, calculation of the cost of the charging station and the price of reliability, and a general procedure were conducted.

Further, the study of Eltoumi et al. [11] was analysed, which presents the most important issues of charging with hybrid power sources, including at the expense of a photoelectrochemical module. The presented model would allow electric vehicles to be charged from a photovoltaic system and facilitate adaptation to intermittent solar energy. To design hybrid energy complexes for a charging station, it is necessary to implement a management strategy by determining the needs of an electric vehicle and the power of a photovoltaic module. It is also important to investigate the operating modes of the charging station and analyse the scheme of the most passable driving schemes since this would reflect the user's preferences regarding charging. The number of electric vehicles in the country also plays a role, since the general regulation of the load profile depends on it. In the study of Wu et al. [12], a model for planning the location of fast charging stations for an electric bus transit system was developed. This can be useful when replacing intercity and intracity buses, moreover, this study compared the costs and convergence of various optimisation planning methods, costs at different time intervals and at different charging capacities. This is also stated by Li et al. [13], in which there is a model of the location of stations considering the combination with renewable energy sources, such as wind and solar energy. The design itself includes a photovoltaic system, wind turbines, a converter, an electrolyser, a backup biogenerator, H_2 and NH_3 fuel cells hybridised with electrochemical and chemical storage devices. This model is suitable for any other locations where metrological conditions (wind speed and solar radiation) are considered. This study considered fluctuations in the power generation of both systems.

Solar energy converters are the most efficient in the modelling of charging stations, especially for the southern part of Kazakhstan, because of the low requirements and short construction time. Wind energy also has its advantages, especially since its cost has decreased in recent years. Wind and solar energy have advantages as well. In fact, solar cells are one of the most efficient renewable energy sources. The popularity of this technology is growing globally every day, and many researchers are working to increase the efficiency of solar panels and on the ways of the cheapest assembly, construction, and maintenance. Solar cells are environmentally friendly, i.e., they do not affect the environment in any way, which in turn is an excellent use for modelling charging stations, otherwise, this problem will cover the world and lead to global warming. In the study of Kumar et al. [19] proposes the joint placement of fast charging stations in the distribution and transport network. The results

showed that this would reduce energy losses in the distribution system by approximately 14.25% on weekdays, and by 18.19% on weekends.

In the study of Kandasamy et al. [20], a system was created that includes wireless charging of electric vehicles. This technology has high efficiency because it works at the expense of solar fuel. In this way, energy is transferred to the power grid for homes, industry, and is also used to charge electric vehicles both in wired and remote mode. The proposed system allows electric vehicles to be charged during the journey. This is an advantage because drivers will no longer have to waste their time at conventional charging stations. Ghotge et al. [21] investigates the use of solar photovoltaic converters for charging electric vehicles at charging stations. The research methodology included an analysis of the state of charge at the exit of electric vehicles connected to the network in the parking lot. The results showed that about half of the vehicles leave with fully charged batteries, and the rest leave with a lower level of charge. In places with the warmest climate, an increase in the share of electric vehicles leaving charging stations is expected.

The successful and most favourable location of the charging station brings convenience to drivers and increases the operational efficiency of the electric vehicle by improving the quality of service of charging stations. That is, an unreasonable choice of the location of the charging station has negative consequences on the economic operation of transport. Thus, the design of a charging station for electric vehicles plays a key role in the economy. For example, in the study of Mehrjerdi and Hemmati [22], a charging station is optimally designed, and the results confirm the minimisation of costs (total investment is reduced by $ 15.75 million over the entire service life) and guarantee a reduction in the peak load of electricity. As a result, referring to this study, it is optimal to connect the solar battery to the energy storage system. Wind and solar energy bring a number of technical and financial advantages, unlike fossil fuels, they have a simple design, low repair and raw material costs.

In the study of Zhang [23], using HOMER software (developed at the National Renewable Energy Laboratory of the United States of America Department of Energy), propose a charging station based on renewable energy sources (where wind is 44%, and solar is 55.6%). This programme considers the current cost of energy, fuel consumption for excess energy, and the amount of renewable energy that is used in the system. HOMER provides an opportunity to calculate the dimensions of a hybrid energy system by conducting tests on the parameters of economic and technical analysis. Furthermore, it is proposed to use the HNSGA-II (Hybrid Non-dominated Sorting Genetic Algorithm II) algorithm to plan the location of the charging station [23]. The results show that this algorithm is the most efficient compared to other algorithms (Multi-Objective Particle Swarm Optimization – MOPSO, Multi-Objective Genetic Algorithms – MOGA). This study considered factors such as the cost of the acquired land for the construction of a charging station, infrastructure, etc. There are also charging monitoring systems that have functions such as storage, display, and analysis of operational data, the ability to check the state of power supply and the quality of electricity. As mentioned above, electric vehicle charging stations in the future may become a large load on the electric grid, and therefore, some factors must be considered when planning the expansion of the network. These factors include the fact that charging stations require a large amount of energy for some periods of time, and they are important and effective loads during the planning of network expansion that need to be considered. However, the ideal design, modelling, location, and operation of charging stations can reduce costs.

3.3 Electric vehicle batteries

The cost of charging an electric car is one of the main factors in purchasing an electric car. Therefore, a reasonable price for charging eco-transport is of great importance. The battery manufacturing process consists of several stages, which begins with the extraction of the necessary minerals and ends with the assembly of the final product with all the necessary connections and electronic components. Upon considering the doubts of potential buyers, it becomes clear that the main one is that after 10 years of service, the batteries of electric vehicles become unusable due to exhaustion of capacity. However, recycling (extraction of raw materials) is one of the chances for a second life for batteries, since discharged batteries can retain up to 70% of capacity. During the recycling, it is necessary to observe safety at the dismantling stage, reduce problems during the process, and develop a recycling route, because, for example, a reaction may occur between Li and oxygen in the atmosphere that can cause an explosion. In general, most routes begin with the stage of dismantling the battery manually or using industrial equipment. Pretreatment and separation of the main components should not be neglected as well, because this can cause environmental and safety problems. There are many types of treatments, such as hydrometallurgical, biohydrometallurgical, electrometallurgy, etc. For example, Harper et al. [24] describes and evaluates existing approaches to the recycling and reuse of lithium-ion batteries in electric vehicles and identifies areas for future progress. Thus, recycling plays a key role in ensuring the security of the supply chain of lithium-ion batteries, as a result of which costs are reduced by 20% [25]. At the daily Nature briefing, it was mentioned that recycled batteries for electric vehicles are as good as new ones [26]. Such topics attract further attention.

Recently, fast charging, which has the ability to provide more than 400 kW of power, has begun to gain popularity. With this charging, electric cars are charged in a maximum of 5 minutes. Wireless charging is also gaining popularity. This technology allows charging an electric car at any necessary time and place [27]. Hussain et al. [28] invented a system that can charge batteries when the vehicle is in motion. The system included wind energy, which contributed to a reduction in battery charging time and the cost of charging the battery of electric vehicles. Batteries with a lithium-metal anode, which has the ability to store and release energy during the charge-discharge cycle, are also gaining popularity. The large capacity of such an anode can approximately double the energy density of a lithium-ion battery, increasing the driving range of electric vehicles compared to cars the movement of which depends on gasoline or other fuel cells [25]. To understand the environmental impact of various types of batteries, Shu et al. [29] examined the environmental impact of $LiFePO_4$ and Li $(NiCoMn)O_2$ batteries during the life cycle. The results of the study showed that $LiFePO_4$ batteries are more environmentally friendly than Li $(NiCoMn)O_2$ ones when used in electric vehicles, and a large input of fossil fuels is not required for their production. Thus, the batteries of electric vehicles can be used as an additional reserve of the power system, where it is possible to store excess renewable

energy and compensate for fluctuations in electricity demand. Such reserves can be applied in emergency circumstances or during unforeseen power outages. Notably, the growing demand for metals for the production of batteries also has social consequences, it is expected that the demand for Li, Co and graphite will increase since they are the main materials for photovoltaic panels and flow batteries. Thus, this would lead to an increase in the pressure on the extraction of natural reserves. Battery recycling can reduce the negative impact on mining activities and be an essential tool for sustainable development in the economy [30-32].

Kazakhstan has invested heavily in research and development of advanced battery technologies, such as lithium-ion, lead-acid and nickel/metal hydride batteries. A number of initiatives focusing on research, development and commercialization of advanced battery technology have been established in Kazakhstan. In 2017, the Kazakh government allocated 614 million KZT for projects designed to support research and development of improved battery technologies for electric vehicles (EVs) and EVs components [14]. Additionally, this fund aimed at increasing investment into lithium-ion technology to become competitive in the global market for advanced Li-Ion batteries for EVs. The Institute of New Energy Technologies was acquired by Kazatomprom to promote energy security related with electrification and mobility innovation processes in Kazakhstan through environmentally sustainable solutions including efficient use of lithium-ion batteries with superior power. This institute invests heavily in lithium-ion battery production and intends to target high value segments of home storage solutions along with EV powertrains, both fields which are expected to drive demand growth worldwide in following decades [27, 33]. Furthermore, Kazatomprom has joined forces with Centrotec Sustainable AG (CEN) – a Swiss firm that develops infrastructure solutions for sustainable mobility – on a subproject package regarding an adaptive charging station installed at Pitkiy Manas Village near Almaty city [14]. It utilizes CEN's patented Energy ring technology as well as robotic systems powered by local renewable sources along with its management system developed by a local company ZUR INSTITUTE. This project also involves the manufacturing process for rechargeable Lib batteries based on zinc sulfide developed at Pitkiy Manas village that will enable much lighter weight energy transfer across any form factors renewable. This illustrates how the government's support plans together with private collaborations continue to shape growth in advanced battery technologies within the Kazakhstan domain.

As the country's residents move from vehicles with an internal combustion engine to electric vehicles, the emissions generated at the stages of extraction and processing of raw materials would acquire further values [34, 35]. These emissions can be reduced by a secondary source of materials. Some materials in electric vehicle batteries are considered critical raw materials. Thus, a considerably higher influx of decommissioned electric vehicle batteries is expected worldwide in the coming years. An increase in the battery life, for example through photovoltaic energy storage, can assist in the purchase of electric vehicles along with the use of renewable energy for self-consumption in households, while reducing the need for fresh raw materials [36]. After the second life, batteries can be recycled to extract valuable materials and reduce dependence on imports from third countries [31, 37]. Therefore, to achieve the Kazakhstan 2050 Strategy, it is necessary to pay attention to the population of electric vehicles and interaction with renewable energy sources. This requires the assistance of the state administration, producers of raw materials, batteries, and cars, and the public.

4. CONCLUSIONS

With the introduction of renewable energy sources for charging electric vehicles, Kazakhstan would receive economic benefits, reduce CO_2 emissions more, and minimise energy costs for transport by up to 100%. Moreover, renewable energy sources provide mobility in cases where there is a shortage of gasoline or its complete unavailability. In this regard, it is necessary to pay attention to the popularisation of electric vehicles, i.e., to attract citizens to purchase electric vehicles. It is necessary to use renewable energy sources when developing models of charging stations. Such technologies have already been introduced in Kazakhstan, besides, the country has a good climate for this, so it is advisable and most efficient to use renewable energy sources, such as solar or wind energy, during development. Thus, it is necessary to raise interest in the recycling of batteries for further sustainable supply chains, as this would lead to a reduction in costs.

The limitations of the presented research are that the process of popularization of electric cars was considered only in Kazakhstan. Prospects for future research are a comparative analysis of the effectiveness of using electric vehicles in different countries to increase economic and environmental benefits.

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