Аңдатпа. Ұсақ бөлшектерді алу үшін арнайы енгізілген қоспаларды **(**модификаторларды) қолдану модификациялау деп аталады. Металды модификациялау дегеніміз - модификаторларды, яғни аз мөлшерде (әдетте пайыздың оннан бір бөлігінен аспайтын) қосымша жасанды кристалдану орталықтарын құруға ықпал ететін заттарды металл балқымаларына енгізу, сондықтан ұсақталған немесе дөңгелек түріндегі бұл бөлшектер құрылымдық компоненттердің пайда болуына ықпал етеді және бұл металдың механикалық қасиеттерін жақсартады.

Мақалада модификацияланған қаптамаларға қойылатын функционалдық талаптар талданған. Кескіш аспапқа термомеханикалық әсер етудің нәтижелері зерттелген. Кескіш аспаптың төзімділігін бірнеше рет арттыруды қамтамасыз ететін сүзілетін катодты-вакуумды-доғалы тұндыруды қолдана отырып қаптамаларды қалыптастыру ерекшеліктері анықталған. Әзірленген композициялық қаптамалардың қатайтылған қабаттардың жеткілікті әрі жоғары физикалық және механикалық қасиеттеріне ие екендігі көрсетілген. Қаптамаларды тұндыру процесінің технологиялық параметрлеріне байланысты қаптама қабаттарының құрылымын бағытты өзгерту мүмкіндіктері анықталған. Қатты балқымалы бақылау аспаптарының қаптамасы жоқ немесе ұсынылған қаптамалармен салыстырғанда әзірленген қаптамалары бар қатты балқымалы аспаптың маңызды артықшылықтары анықталған.

Түйінді сөздер: қаптама, құрылым, фазалық құрам, микроқаттылық, төзімділік.

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PERFORMANCE CHARACTERISTICS OF ELECTRIC BUSES

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Abstract. The depletion of fossil resources, energy dependence, rise in fuel prices, and environmental issues caused by fossil fuel vehicles, combined with advancements in battery technology and manufacturing processes, have accelerated the transition to electric vehicles. Evidence indicates that electric buses play an important role in public transportation if we are to reduce climate change and the environmental effects of fossil fuels. Several electric alternatives are currently operational, and the debate about which is the best is generating a lot of interest. This article examines the different performance characteristics of three types of electric buses: hybrid, fuel cell, and battery. Based on simulation models and operational data provided by various scholars in various contexts, the economic, operational, energy, and environmental characteristics of each technology are examined in depth. The study creates a systematic evaluation of electric buses based on a side-by-side analysis of 16 features that help people make better decisions. According to the report, the selection of electric technology is highly dependent on the operational background and energy profile. Furthermore, it emphasizes that hybrid buses would not have a substantial reduction in GHG emissions and are only ideal for short-term goals as a stepping stone toward complete electrification of transportation. While battery and fuel cell buses are arguably capable of meeting current operational needs, the initial investment is still a significant barrier. Given the anticipated advances in battery technology and the trend to use renewable sources in power generation, the Overnight Battery Electric Bus is advocated as the most appropriate option for bus transit contexts given the expected improvements in battery technology and the trend to utilize sustainable sources in electricity generation.

Keywords: electric bus, hybrid bus, battery, fuel cell, ecology.

The volatility of oil prices, the Kyoto Protocol commitments, and initiatives to minimize transit emissions are pressuring policymakers to adopt new technologies that will replace oil-dependent mobility. Despite major efforts to implement requirements to minimize emissions from conventional internal combustion engines, expected reductions are unlikely to achieve Kyoto protocol emission goals. Alternative technologies are needed if we are to reduce the emissions footprint of the road transport sector. Even though various technological solutions have been implemented in recent years, oil-based mobility still holds the lion's share of the transport industry, and market penetration of alternative technologies is still very low.

The introduction of modern road transport alternatives is dependent on a number of factors that are well covered by the traditional petrol/diesel counterpart. These elements include, but are not limited to, energy logistics, cost-benefit analysis, infrastructure, and public acceptance. In this regard, public transportation has a higher potential for significant market penetration of alternative technologies, especially in the context of city buses. Bus transportation, among other things, has fixed routes, centralized depot sites, and shared facilities, all of which are conducive to the introduction of alternative technologies. In this environment, the technology could be operationalized, evaluated, and optimized while lowering emissions. Several electric powertrains for urban buses have recently been introduced to the market. Each has distinct advantages that could be leveraged to reduce emissions to the greatest extent possible. However, choosing an appropriate powertrain for each context is dependent on a variety of factors such as cost, network structure, energy source, and driving conditions. For each technology to be used optimally, a trade-off between different features is needed.

Several studies have been conducted to model and measure the technoeconomic and environmental impacts of electric buses. These studies are primarily focused on three domains: environmental, energy and economic. In a nutshell, environmental models look into possible GHG emission reductions from electric buses, energy usage models look into electric bus energy efficiency, and economic studies look into the cost-benefit analysis of introducing electric buses in transit.

This research expands on previous efforts, with the aim of offering a thorough analysis of electric bus features and their potential as a substitute for diesel buses in transit operations. The research focuses on Hybrid Electric Buses (HEB), Fuel Cell Electric Buses (FCEB), and Battery Electric Buses (BEB). Initially, an overview of electric powertrain configurations is given. Section three illustrates market predictions. Section four provides a brief examination of the economic, environmental, operational, and energy characteristics of electric buses. In section five, the results are used to produce a comprehensive comparison of electric buses and diesel buses on 16 efficiency features of electric buses. Finally, a concluding segment discusses the future of electric buses in transit operations.

An overview of the electric bus technology

The degree of electrification used by electric buses varies depending on the design of the propulsion system. Hybrid Electric (series and parallel), Fuel Cell Electric, and Battery Electric (overnight and opportunity) are a few examples. All systems, with the exception of parallel hybrid, share the central principle that propulsion energy is generated from an electric traction drive system. The primary distinction between these technologies is the source of power for the electric motor.

To provide traction power to wheels, hybrid electric technology employs both an internal combustion engine (ICE) and an electric motor (EM) in different configurations [1]. Hybrid buses can be designed in two ways: series and parallel. Both engines (ICE and EM) are paired to propel the vehicle in a parallel configuration. Traction power could be obtained separately from the ICE and the EM, or by combining the two. In series mode, the on-board ICE, also known as the generator, generates electricity that is either transferred to the EM or stored in an on-board battery box. There are some other configurations for hybrid buses that are dependent on the ICE's fuel supply, such as gasoline, diesel, natural gas, and biofuel. Hybrid buses are frequently designed based on the degree of hybridization needed. The energy production ratio from the EM and the ICE are referred to as high and low hybridization ratios, respectively. The creation of a plug-in hybrid technology has resulted from the demand for a high hybridization ratio. The plug-in hybrid configuration is similar to the series hybrid configuration, but it adds the ability to recharge the on-board battery with an external electric source. For a limited range, this provides an electric-only drive alternative without using the ICE/generator.

Alternative methods for electrifying buses include fuel cell technology [2]. The electric motor in a fuel cell is powered by electricity produced from fossil fuel. Unlike traditional ICE, which uses fuel to produce dynamic movement, fuel cell technology uses an electrochemical method to generate electricity from fuel. The chemical energy contained in the fuel cells is converted into electrical energy during this phase. Fuel cell technology could be used to supplement an electric battery in a hybrid mode, or as the primary power source for an electric motor.

The Battery Electric Bus, also known as a pure electric vehicle, is powered by electricity contained in an on-board battery kit [3]. This technology's engine design contains no mechanical parts. The Battery Electric Bus is available in two configurations: opportunity and overnight. The range and charging time variations between the two forms are what distinguishes them. The opportunity electric bus has a smaller battery kit that has a restricted range (30-50 kilometers) and a maximum charge (80% – 100%) in 5–10 minutes. The overnight electric bus, on the other hand, has a larger battery kit with a range of up to 300 kilometers and a much longer charging time (2– 4 h).

Electric bus market trends

In recent years, the market share of electric buses has steadily increased. In 2012, electric buses accounted for 6% of new bus sales worldwide. This share is divided among key players around the world, including Asia Pacific, Europe, North America and South America. Several attempts have been made to forecast the future market share for electric buses, most notably Frost and Sullivan's efforts [4]. According to their projections, electric buses will account for 15% of the global market in 2021, with a compound annual growth rate (CAGR) of 26.4%. The market distribution of electric buses, on the other hand, indicates that the Asia Pacific region, primarily China and India, will dominate the electric bus market with a CAGR of 6.3%. This compares to 3.9% in Europe, 3.6% in North America, and 6.3% in South America. Taking the Asia Pacific bus market share (40.9%) into account, it is estimated that 75% of all electric buses will be deployed in Asia Pacific.

Furthermore, the 2021 forecast indicates that, while electric buses will dominate the North American industry, market penetration will be primarily powered by hybrid technology. According to Pike's estimates [5] the industry profile shows that hybrid buses will account for 73% of the electric bus market. BEB and FCEB would have a limited market share, with 8% and 19%, respectively. However, all market forecasts are based primarily on the maturity of existing technologies, which is subject to substantial change.

Performance features for electric buses

Electric buses vary from diesel buses in many operating aspects [1]. These operational features must be considered and weighted for the technology to be successfully implemented. These features include environmental aspects (GHG emissions, noise, and air quality), energy aspects (energy source, energy consumption, and fuel efficiency), operational aspects (range, acceleration, charging time, availability, and infrastructure) economic aspects (capital cost, infrastructure investments, maintenance, and operational costs).

Environmental performance

Both researchers and service providers have paid close attention to the environmental efficiency of various developments in recent years. The environmental advantages of electric powertrains are advocated as the primary reason for electrifying mobility options. Environmental performance is introduced in the literature in the context of a Well-to-Wheel (WTW) calculation of Green House Gas emissions (GHG). The WTW evaluation incorporates induced emissions in two stages: Well-to-Tank (WTT) and Tank-to-Wheel (TTW). WTT tests GHG emissions from fuel (such as gasoline, hydrogen, and electricity) during both the processing and delivery levels, while TTW measures GHG emissions from fuel at the consumption stage. [6]

The well-to-tank evaluation includes quantifiable estimates of GHG emissions during energy generation and delivery. The evaluation is carried out clearly by identifying energy processing processes, feedstock, and delivery routes. Several models have been produced to measure the WTT GHG emissions due to the large difference in energy processing practices (i.e. fossil fuel, renewable, and biofuel) and transport pathways (i.e. road, rail, pipelines, and on site). In the United States, the GREET model is used, while in Canada, the GHGenius model is used, and in Europe, the RED model is used. Other trials have since been conducted in other contexts. According to these models, gasoline fuel produces the lowest WTT GHG emissions per mega-joule (MJ) as compared to electricity (EU-mix) and hydrogen (NGSR) fuel. It is also clear that the process of fuel processing has a direct effect on the resultant GHG emissions (i.e. the electricity profile in China, EU, and US). Renewable energy-based manufacturing processes, it is claimed, are the ultimate means of achieving zero WTT emissions. However, the WTT assessment only gives a partial picture of overall environmental efficiency.

Tank-to-Wheel assessment of GHG emissions, on the other hand, estimates the local emissions emitted during bus service. Since TTW findings are extremely context sensitive (i.e. traffic conditions, noise, average speed, and number of stops), TTW assessments are usually performed using one of two methods: operating data or vehicle modeling models. The TTW results for a standard 12-m bus indicate that both FCEB and BEB operate with zero local GHG emissions, while the GHG performance of HEB is dependent on the degree of hybridization of the propulsion. The average GHG emissions from a diesel–HEB are 790–970g Co_2eq/km, while CNG–HEB emissions are 700–800g Co_2eq/km.

The Well-to-Wheel GHG assessment of electric buses gives an analysis of each technology's environmental efficiency. It demonstrates that both FCEB and BEB have a significant ability to mitigate GHG emissions. HEB serial and parallel contribute 20% and 13% of the total GHG reduction, respectively. FCEBs using both NGSR and WE hydrogen production methods lead to a 74% decrease in GHG emissions as compared to diesel buses. In the case of BEB, however, the energy pathway has a substantial impact on overall environmental efficiency. The BEB focused on an EU-electricity mix reduces GHG emissions by 41%. BEB with a renewable-based energy supply is regarded as the optimal option for ZERO GHG transit.

Energy performance

Electric buses use a variety of energy sources. BEB uses energy, FCEB uses hydrogen, and HEB uses fossil/bio fuel [7]. Each energy supply has distinct characteristics that affect the efficiency of electric buses. Energy production, energy conservation, and energy consumption are examples of these characteristics. These are regarded as the primary standards for maximizing the performance of electric buses because they offer a direct indicator of total energy consumption. The net volume of energy needed for one kilometer of travel is often used to calculate energy efficiency.

Operational performance

Range & charging time.

In general, range is the primary impediment to the attractiveness of electric mobility in many circumstances. The term "Range Anxiety" has often been echoed as a weakness of electric bus operating features. The phrase applies to the electric range's unsuitability for everyday travel practices.

Despite the fact that the problem has been repeatedly raised in the literature, many electric buses have already discussed range issues. The HEB has a range comparable to diesel buses, and the parallel hybrid has an additional all-electric range of 10 km. In addition, FCEB has a full electric range comparable to diesel buses, with an average of 4300 km. However, there is a range problem in the BEB category: overnight BEB has a range of 250 km on a single charge, while opportunity BEB has a range of 30–40 km [8].

Recent studies have merged refueling time and range in a single indicator to solve range limitations due to their collective direct effect on service scheduling. This metric is known as operational flexibility [8]. According to Miles and Potter, battery electric buses are not versatile in service due to the impact of charging time on schedule [9]. They have also stated that, due to charging time and range constraints, two Battery Electric Buses would be needed to replace a single diesel bus while keeping the same schedule. However, this analysis contends that, when considering the additional range for 5 minute refueling/recharging (using the diesel bus as a benchmark), all electric buses perform similarly to their diesel counterparts, with the exception of the Overnight BEB. The Opportunity BEB has a reasonably good results, with a range of 20/30 km per 5 minutes, compared to only 4 km for the Overnight BEB. There are currently many schemes in place to address the long charging period for Overnight BEB. To address the long charging time for batteries, some operators have implemented battery exchange schemes/stations. In comparison, BEB gains from opportunistic charging at stations/stops during passenger boarding and/or alighting. It is claimed that opportunity BEB can run continuously for 24 hours.

Infrastructure.

Infrastructure is another important operational factor for electric buses. Hybrid buses do not need any special infrastructure and can run on existing infrastructure [10]. A hydrogen filling station is needed by the FCEB. To reduce the cost and GHG emissions of the hydrogen route, it is proposed that such a station be located on-site at the depot. Several infrastructure installations are needed for the BEB category. BEB Overnight needs a super/fast charging station(s) at the depot, as well as an additional battery supply if a battery-swapping scheme is in operation. BEB opportunity will operate with a variety of charging infrastructure options, including charging spots, overhead charging poles, and inductive charging. Although the construction of charging spots/poles does not necessitate significant changes to the current infrastructure, the requisite large number and distribution of these spots acts as an obstacle to the Opportunity BEB's implementation. Furthermore, the effect of charging stations on the power grid is viewed as a barrier to the implementation of Opportunity BEB, especially in large metropolitan areas.

Other operating characteristics, such as availability, acceleration, vibration, and noise, demonstrate that electric buses perform similarly to diesel buses. Since there are no mechanical components, the electric bus produces less noise and vibration and has a reasonably reasonable acceleration (10 s 0–30 km/h vs. 7.5 s for diesel) [8]. Recent performance data also shows that, when compared to diesel and hybrid buses, FCEB and BEB buses have an average of 85% and 90% availability (operating according to the expected schedule) [11].

Economic performance.

Total cost of ownership (TCO) has been described as a major impediment to the adoption of electric buses [12]. TCO covers the cost of manufacture as well as maintenance, operation, energy delivery, utilities, emissions, insurance, and end-of-life. In the literature, TCO has been estimated using operational data or life cycle analysis models. Despite numerous attempts to quantify the TCO of electric buses, it is clear from the literature that there is a great deal of ambiguity in the calculation of TCO. TCO measurement is heavily reliant on operational and logistical factors, for example, fuel price (diesel, energy, and hydrogen) plays a significant role in TCO estimations.

Differences in pollution cost/penalty and taxation policies also have an effect on TCO.

All electric buses are more expensive to manufacture than their diesel counterparts. The additional expense is due to the cost of electric components (such as the battery kit, electric motor, and auxiliary system). It is clear that there is no major price difference between parallel and series hybrid buses. Because of the smaller on-board battery kit, the opportunity bus is less expensive than the overnight bus for BEB. The FCEB is the most expensive electric bus on the market, with an estimated manufacturing cost of $2 million USD. Electric buses outperform diesel buses in terms of maintenance costs. BEB offers an annual cost savings of 80% in operating costs. Although HEB, series, and parallel reduce operating costs by 8–15% on average. However, in terms of infrastructure costs, the opportunity BEB is regarded as the most costly. Despite the fact that FCEB and Overnight BEB need significant infrastructure modifications for filling/charging stations at depots, the Opportunity BEB necessitates a higher density of charging stations along roads. According to estimates, one charging station should be located every 10–20 kilometers.

Based on operational data from electric buses throughout Europe, the Fuel Cells and Hydrogen Joint Undertaking [8] established TCO estimates. The TCO estimates took into account a wide range of metrics, such as the costs of purchase, borrowing, activity, facilities, and pollution penalties. Based on 60,000 km annual mileage and a 12-year bus lifespan, their findings indicate that the Overnight BEB is the most expensive electric option for urban buses in terms of total cost of ownership, followed by the FCEB and the Opportunity BEB. Both series and parallel hybrids have registered TCOs that are nearly identical to diesel buses. Other studies, however, have argued that the TCO of electric buses is extremely responsive, not only to planned cost reductions of electric components (i.e. battery price, auxiliary system), but also to the service's utilization level. Several studies have found that under high and even moderate utilization scenarios, electric buses can be a more cost-effective option than diesel and CNG buses. According to the FCH-JU [8], the TCO for some electric buses would drop dramatically by 2030, with an average of 30–50% for FCEB and BEB (Overnight & Opportunity). The TCO for HEB (series and parallel) and diesel buses is also projected to fall by 1–5% by 2030.

Electric buses performance review

In the sense of bus transit, several requirements guide the decision-making process for choosing a viable alternative technology. A provided technology may be appropriate for one context but not for another. Given the multi-criteria nature of the issue and the trade-offs that must be made during the decision-making phase, a comparison of various technologies is critical in order to better educate service providers and decision-makers on the implementation of viable alternatives.

Several conclusions can be drawn from the side-by-side comparisons. In every way, hybrid buses operate similarly to diesel buses, with the exception of GHG emissions and energy consumption. It is clear that HEB reduces GHG emissions by 20.8% on average and saves 26.1% on energy consumption. Fuel cell buses have a high initial cost and a cumulative cost of ownership that is 188% higher than a diesel bus. Fuel cell buses have similar operating features to diesel buses while emitting zero local emissions when installed with minimal infrastructure. Renewable-based hydrogen FCEB leads to a 75% reduction in GHG emissions and a 27% reduction in energy consumption, which is significantly higher than NGSR-based hydrogen FCEB, which contributes to a 73.8% reduction in emissions and a 15.4% reduction in fuel consumption.

With zero local emissions and a fair price tag, Opportunity Battery Electric Buses could be viewed as the most appealing choice. The total cost of ownership is 52.1 % higher than in the case of a diesel bus. However, in order to meet operational requirements, especially range constraints, Opportunity BEB necessitates major infrastructure installations. Renewable-based electricity reduces GHG emissions (98.4 %) and energy consumption (50 %), while the EU-mix electricity profile leads to a 41.1 % reduction in GHG emissions and a 9.7 % reduction in energy consumption. Overnight BEB has adequate range and operating features, but its overall cost of ownership is 161.7 % higher than that of a diesel bus. To address the long charging time, battery swap schemes are currently recommended. With no local pollution, Overnight BEB emits and consumes the same amount of energy as Opportunity BEB. Both are affected by the electricity profile.

This study contends that the Overnight Battery Electric Bus is theoretically the most desirable electric powertrain for bus transit based on the analysis. This point is supported by three pillars: a) The transition is unavoidable; due to the existing usage rates of fossil fuel resources, a shift in energy profile toward renewable energy is unavoidable. Oil production is expected to decline after 2030. Oil reserves are predicted to fall to 20% of current levels by 2040, while gas and coal reserves are expected to last another 20 years. As a result, renewable energy, especially electricity, will be the most desired source of energy in the post-oil era . b) Gaps, inconsistencies in steps; hybrid and internal combustion technologies are achieving their full potential. While steady small progress toward pollution reduction is anticipated in the future, it will not be sufficient to meet global emission goals. Hybrid technology is often viewed as a bridge to complete electrification, while fuel cell technology is often viewed as a short-term solution due to its reliance on fossil reserves. Having said that, battery technology is projected to gain a substantial share of the mobility market. Huge advances in battery technology are anticipated, which can triple or quadruple vehicle range when charging in a fraction of the time (i.e. Zn-air batteries). c) Context sensitivity will no longer be relevant; given the two preceding points, the future energy profile will be identical in different contexts, and thus context will have less effect on the operational features of electric buses, especially from an environmental standpoint. As a result, this study contends that integrating Overnight BEB buses in the form of bus transit would support both short-term emission goals with zero local emissions and long-term alignment with the projected energy profile. This would create incentives for research and development to improve technology in terms of affordability and dependability.

Conclusion

This study provides an overview of electric bus technologies in the transit context, with a focus on three in particular: hybrid, fuel cell, and battery. The study is told by simulation models as well as operational data from the literature, and it develops a comparative overview of 16 performance features for electric powertrains. Overall, this analysis offers a unified assessment of the strengths and features of electric bus technologies, which helps to guide decision-making and future research directions. The study looked at four aspects of electric bus performance: economic, environmental, operational, and energy efficiency. Several messages have emerged, the most important of which is that the efficiency of all electric buses is highly sensitive to the energy profile and operational demands. As a result, a single technical solution would not meet the diverse organizational needs of transit systems. That being said, a Battery Electric Bus (BEB) coupled with a renewable source of energy is arguably the ideal option, providing zero net emissions as well as a variety of range and charging time configurations (opportunity & overnight). However, since countries have a mixed-source electricity generation profile, the environmental benefits of BEB are dependent on the amount of GHG generated during electricity generation. Hybrid buses may be seen as a first step toward complete electrification. According to the study, hybrid powertrains do not have substantial reductions in both energy consumption and GHG emissions. However, because of the strict operational requirements in transit service, especially in terms of operating hours and charging/refueling time, hybrid buses are viewed as a viable option that meets these operational constraints. Fuel cell technology may be viewed as a viable alternative in situations with longer driving ranges; however, the review indicates that fuel cell technology has a poor market penetration. The slow speed could be attributed to major manufacturers' current R&D emphasis on battery electric technology. Although the electric powertrain has different features than its diesel equivalent, the demands of transit service are well-aligned with diesel powertrains. As a result, if we are to encourage electric powertrain technologies in the transit context, we must reconsider the design parameters of transit service. Future research that combines electric bus functionality with network/schedule optimization will be critical in defining a route toward full transit electrification.

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ХАРАКТЕРИСТИКИ ПРОИЗВОДИТЕЛЬНОСТИ ЭЛЕКТРИЧЕСКИХ АВТОБУСОВ

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Аннотация. Электрификация общественного транспорта играет важную роль в решении современной проблемы изменения климата и растущего воздействия ископаемого топлива на окружающую среду. В настоящее время действуют несколько электрических альтернатив, и споры о том, какая из них лучше, вызывают большой интерес. В данной статье исследуются различные эксплуатационные характеристики трех типов электрических автобусов: гибридных, основанных на топливных элементах и аккумуляторных. На основе имитационных моделей и эксплуатационных данных, предоставленных различными учеными, глубоко исследуются экономические, эксплуатационные, энергетические и экологические характеристики каждой технологии. В результате исследования было выявлено, что выбор электрической технологии во многом зависит от производственного фона и энергетического профиля. Также, после проведенного сравнения технологий, аккумуляторный электрический автобус рекомендуется как наиболее подходящий вариант для автобусных перевозок.

Ключевые слова: электрический автобус, гибрид, аккумулятор, топливный элемент, экология.

ЭЛЕКТРЛІ АВТОБУСТАР ӨНІМДІЛІГІНІҢ СИПАТТАМАЛАРЫ

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Аңдатпа. Қоғамдық көлікті электрлендіру климаттың өзгеруі мен қазба отынның қоршаған ортаға әсерінің қазіргі заманғы мәселелерін шешуде маңызды рөл атқарады. Қазіргі уақытта электрлі көліктің бірнеше баламасы бар және қайсысы жақсы екендігі туралы пікірталас үлкен қызығушылық тудырады. Бұл мақалада электрлі автобустардың үш типінің әртүрлі сипаттамалары қарастырылады, олар: гибридтік, отын элементтеріне негізделген және аккумуляторлық. Әртүрлі ғалымдар ұсынған имитациялық модельдер мен пайдаланушылық деректеріне сүйене отырып, әр технологияның экономикалық, пайдаланушылық, энергетикалық және экологиялық сипаттамалары терең зерттеледі. Зерттеу нәтижесінде электр технологиясын таңдау көбінесе өндірістік фон мен энергия профиліне байланысты екендігі анықталды. Сондай-ақ технологиялар салыстырылғаннан кейін аккумуляторлық электрлі автобус жолаушыларды автобуспен тасымалдаудың ең қолайлы нұсқасы ретінде ұсынылады.

Түйінді сөздер: электрлі автобус, гибрид, аккумулятор, отын элементі, экология.