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Smart Steps Towards Sustainable Transportation: Profitability of Electric Road System

Hasan Huseyin Coban

Abstract—**The global average temperature has increased by about 1°C compared to pre-industrial times and the temperature increase continues. The effects of climate change are already affecting living conditions on Earth. Through the Paris Agreement, the countries of the world have committed to limit global warming to below 2°C compared to pre-industrial times and to make efforts to keep the increase below 1.5°C. The transportation sector accounts for about 15% of Turkey's greenhouse gas emissions, and more than three-quarters come from diesel fuel. Already in ten years, transport emissions must be reduced by 70% according to the national targets. It is about both reducing emissions by 2030 but also ensuring that we are completely emission-free by 2050. The vast majority of emissions in the transport sector come from road traffic. Electric vehicles have emerged as the most promising solution to energy and environmental security concerns. However, a major constraint for electric vehicles has been the limited range and fast charging capacity. Various electric road technologies have great potential to reduce dependence on fossil fuels, reduce greenhouse gas emissions, reduce air pollution and reduce noise in urban areas. This article proposes to discuss the inductive and conductive charging system and required system configuration in the concept of electric roads for electric buses. The model solution algorithm is designed and it is validated on the E-bus route R40 in Kayseri city, Turkey. It is found that if an electric road system is used instead of a diesel bus for a bus line route of 35.5 km, it will amortize itself in 10 years.**

Index Terms—**Electric Road System, Design process, Sustainability, Electric bus.**

I. INTRODUCTION

THE HEAVY traffic is now increasing rapidly, contributing to ever higher greenhouse gas emissions [1]. While some people defend the transfer of people and heavy loads to rail, there are other conceivable alternatives. One is to electrify road transport instead. An electrified road system, "electric roads", or "Eroad", or "electric road system" (ERS) where electrical energy is transferred during movement from the road to vehicles for both propulsion and charging, has great potential for reduced dependence on fossil fuels and increased energy efficiency in the transport sector.

Electric vehicles (EVs) are seen by many as a possible solution to reduce harmful emissions to the environment, reduce dependency on fossil fuels and increase energy efficiency in the transportation sector [2]. Unfortunately, most environmentally friendly energy storage systems, such as batteries, contain a lower energy density compared to fossil fuel, which has a significant impact on the vehicle's range [3], [4]. A battery large enough for long-distance transport often results in a significant increase in cost and weight, which means a reduction in possible transport volume. An alternative to battery-powered operation is to transfer energy from the road to the vehicle for both propulsion and charging during movement. Expanding the ERS between larger urban areas means that the majority of the route can be powered by electricity from the road network, and the remaining route can be powered by a smaller battery.

Road transport uses electricity as fuel and the technology used to transmit electricity also includes a properly designed infrastructure that is lacking today. This study shows that the expansion of the infrastructure for the supply of electricity to buses is not as complex and costly as the expansion of the railway.

Road freight accounts for nearly one-fifth of annual global oil consumption [5]. Today, the climate problem is one of the most current issues in society. The EU aims to reduce its emissions by 80-90% by 2050 compared to 1990 [6]. The ministry of environment and climate change aims for Turkey's net emissions to be zero by 2050 and for transportation to reduce its emissions by 70% by 2030. In addition, Turkey should also be the region's first fossil-free welfare state. To meet these demands, more and more people are switching from fossil fuels to alternative fuels, including electric cars.

The EV is nothing new, and one of the reasons it hasn't been adopted is because of the time-limited range when refueling on the go. As the vehicles are electric, there is a need for charging on long journeys. Today's market-leading passenger cars have a range of around 400km and can be quickly charged to 80% in 30 minutes at selected locations [7]. For longer, uninterrupted transport, fast charging is not an option, especially when it

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comes to commercial traffic, as there will be too many and too long charging breaks.

The transition to battery-powered buses for electric operation adapted to both electrified roads and stationary charging represents a technological leap that could be significant in reducing carbon dioxide (CO_2) emissions from road transport. The technology is at an early stage, making profitability assessments of infrastructure investments more uncertain than they usually are. A discussion of ERS and their potential to reduce dependence on fossil fuels can be found in the report [8], [9], which is the source of this article and the investigation into fossil-free vehicular traffic.

This study aims to investigate the electrification of municipal buses in Kayseri province. Through this study, it is to lay the foundation for a project on the electrification of bus traffic in the urban area of Kayseri by highlighting the key questions to be resolved. This is expected to contribute to better air quality in the city and Turkey's achievement of its environmental targets by 2050 [10]. The other aim of this study is to investigate what technical changes should be made in the infrastructure of the city in order for electric buses (EBs) to be charged and to develop a concept for a new road design that supports the future development of electrified road technology for a bus line with intensive human transport consistent with its sustainable intentions. In addition, the economic feasibility of constructing an electric road along the bus line using small batteries will be demonstrated. This study does not cover the electrification of bus lines outside the urban area, such as rural and regional buses or school transport. In addition, of course, the cost of the actual investment in the ERS and the proportion of fuel-powered vehicles that switch to electric operation play a large role in the profitability assessment. This is described in the analyzes by varying the investment cost in the various calculations and by varying the number of fuel-powered vehicles that switch to electric operation. Electric roads are a relatively new field, and articles and reports in the literature have been used to find information [8], [11]–[14]. Relevant literature was used to find information about EBs and especially the characteristics of batteries.

Chapter 1 is a short introduction about why the study is being carried out and what is to be done. Chapter 2 is a description of the present and future bus systems in Kayseri. Routes, route length, departure frequency, and other important information are given for the selected bus line. A comparison of fuel consumption and emission rates is presented to motivate the conversion from internal combustion buses to EBs. Chapter 3 specifies all the components required to build an ERS and is discussed from an economic point of view. Chapter 6 presents all the results from the study and the possible future study topics.

II. The Principle and Technology of EB and ERS

This section presents the available technology for EBs and the infrastructure needed to operate different types of EBs. Then it briefly explains the theory behind how energy can be extracted from the road and how each technology is used to deliver energy to buses.

A. Electric Buses

In this section, focusing on city buses, diesel buses, and battery-powered buses are examined. By comparing them, energy consumption, energy storage, usage, energy transfer, and environmental effects are examined. EBs are generally divided into the following categories: electric hybrids, plug-in hybrids, and EBs. This study mainly targets EBs. The advantages and disadvantages of EBs are listed below [15], [16].

Some advantages of EBs are:

- More enjoyable trips. The quieter and smoother operation of EBs provides a more enjoyable environment for both bus drivers and passengers.
- No exhaust pipes. This is how you can limit or completely eliminate greenhouse gas emissions from the bus itself.

Some disadvantages of EBs are:

- Limited range. The range will be longer if the bus' battery is quickly charged along the route. However, using the ERS by using a smaller battery instead of a large battery will eliminate the range problem.
- In cold climates, it affects the range more directly because the batteries have lower capacity than in hot regions, and indirectly because the heating in buses requires more energy.
- Less flexibility. When using an EB, it is necessary to plan the route in advance, each charging strategy changes the range capacity of the bus. The EB, which is suitable for one bus line, may not be suitable for another line at all.
- Infrastructure is required. Charging stations are needed, they are all charged at the last stops or depot, but some have to be recharged along the way, usually with the help of pantographs at the main stops.
- Risk. The electric technology applied to buses is still relatively immature, unlike conventional Internal Combustion Engine (ICE) technology which is mature and well-understood.
- Cost of capital. Especially if the infrastructure does not exist, electrification will be very expensive. EBs are more expensive than diesel buses in terms of price, maintenance, and repair.

B. The design of the EB charging infrastructure

This question is described as one of the most important aspects when purchasing EBs. There are four main options for how charging infrastructure can be designed: depot charging, additional charging, and ERSs [17]. Charging can be done either conductively (via contact) or inductively (wireless).

Plug-in charging [18]: The battery is charged by manually connecting a cable from a charging station to the bus as a plug-in and this technology is mainly used for depot charging. The driver will need to get out of the vehicle and plug the cable into the bus, but the installation is simple and the plug is less affected by winter weather compared to other charging methods.

Pantograph charging [17]: There are different charging methods in this category. There is a mechanical arm that connects the bus to the electrical grid and this arm is controlled by the bus driver from inside the bus. Pantographs can either be overhead or placed under the bus. If the pantograph is on the bus, it has a pair of rails to which it is attached, and the mechanical arm lifts it towards the mast. There is also the possibility that the pantograph can be placed at the bottom of the bus and connected to the rails on the ground.

Wire charging [19]: Another automatic conductor charging method is to charge the bus via a wired system suspended above the road. It is a concept similar to a trolleybus or tram, except those buses can automatically connect and disconnect from this system and run freely on battery power for a while.

Inductive charging [18]: The last category is wireless inductive. Here charging takes place wirelessly along the way, either while standing still or while working where the induction comes from coils etched about 5-10cm below the road. This can have large transmission losses in the charging concept and is an immature technology concept.

The amount of time needed to successfully connect the desired electrical capacity to the facility depends on many different parameters. Care should be taken to ensure that detailed plans, terrain, transformers, etc. are ready and suitable for the purpose. Depot charging and plug-in are the most common in the world today and the system that is the cheapest to introduce and requires the least adaptation of the infrastructure in the urban area. It is also more flexible as the buses can run on all routes. The main disadvantage is that it requires larger batteries with a higher capacity and it is not certain that the battery will last a full day of driving.

C. *Typical charge effects*

EBs adapted to parked or end-stop charging require very large batteries to travel as far as possible on a single charge; which usually means a more expensive purchase price for these buses, but cheaper and simpler infrastructure as all charging takes place.

TABLE I
INSTALLATION PRINCIPLES AND CHARGING EFFECTS FOR DIFFERENT CHARGING TECHNOLOGIES

Charging technology	**Power (kW)**	**Installation**
Electric road system	Conductive: 50 - 60	Electrical panels are needed at some connection points along the bus line.
	Rail in road: 200 - 800	
	Inductive: 25 - 100	
Plug-in	30 - 150	Common grid station for the depot. Connection with cable at each depot location.
Pantograph	300 - 700	Charging at a post, beam, or gantry either at the end stop, terminal, or dedicated charging point in the vicinity of the end stop.
Induction (Stationary)	200	Charging plate under the ground (asphalt).

Charging in the depot can be done in several different ways, but plug-in charging is generally used because buses charge longer at night. In case any bus needs additional charging during the day, it may also be necessary to have a few quick chargers in the tank. Longer distances and high-frequency city traffic that require charging during the day can be difficult to implement tank charging. This is mainly because it means more empty driving during the day as buses need to be recharged. It can also mean extra buses that replace buses that need to be charged.

Table 1 shows the typical power ranges of different charging technologies and their applications around the world. The effects in Table 1 can be adjusted for how long the buses need to be charged.

D. *Review of Electric Road System*

Ten years ago, when ERS systems [8], [11] began to be discussed, the world was focused on developing batteries. Some investors saw it a little differently, they wanted a solution that could connect vehicles to the network 24/7 and saw the road as a solution. Charging is a matter of time, so the most natural way is to turn the road into a charging asset. There are 1.4 billion vehicles on the planet, and there is no way to provide one charger per vehicle and this is not sustainable [20]. It needs a common charging platform and the key is inductive or conductive charging via ERS. Electric road technology can charge any electric vehicle, bus, truck, or taxi while driving or parking in any weather conditions. Because vehicles do not need dedicated downtime for charging, the fleet needs to address various industry challenges, such as increasing operational uptime. It also increases the load range, which can be basically unlimited, balancing the demand in the electricity grid by providing day and night charging. The participation of several different actors and systems is needed for electric roads to become a functioning transport solution that produces good climate effects (see Figure 1).

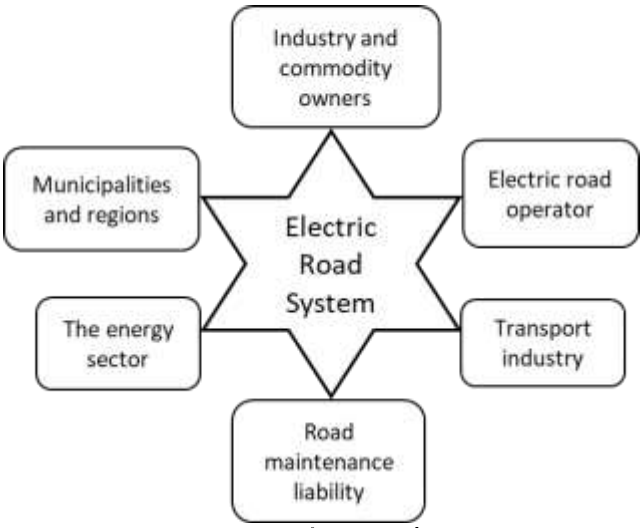

Fig.1. The system of ERS

There are different technologies for electric roads today that can be divided into 3 main types, based on energy transfer from a road to a vehicle [8], [19]:

• inductive transmission via electromagnetic fields from the road body,

• conductive transmission via overhead line,

• conductive transmission via tracks or conductors in the road.

Induction is a way of wirelessly transferring energy between the source and receiver. The electric road uses induction to charge EVs moving on it, via receivers mounted on the underside of the vehicles. A system common in our households; wireless phone chargers and induction cookers are examples. Induction technology is used to charge the electric vehicle in the same way as the phone, it is done by static induction, which means that both the source and receiver are stationary during the transfer of energy. However, what is under development is to use similar technology with the difference that the receiver (vehicle) is in motion and thus dynamic induction is achieved. This technology works considerably the same as static induction charging, the challenge lies in ensuring safety.

Conduction is the opposite of induction and deals with the transfer of energy through physical contact between the source and the receiver. There are three ways to charge vehicles conductively while driving; power supply above the road, power supply beside the road, and power supply on the road. This means that energy is transferred from a charging rail in the road to the vehicle via a folding collector under the vehicle. The principle can be compared to the electric propulsion of trains, a lever is opened and the vehicle is in contact with the power source at the same time as it is in motion. One challenge with the transmission - especially in pantographs on the road - is that trucks and cars have large height differences. A passenger car will need a long arm to reach the same powerline from which the trucks will be powered.

There are big differences between EBs adapted for different charging strategies. The different available ERSs for EBs are shown in Figure 2 and can be divided into 3 different categories. These categories are used by different countries around the world (see Table 3) to help cities with different conditions charge EBs.

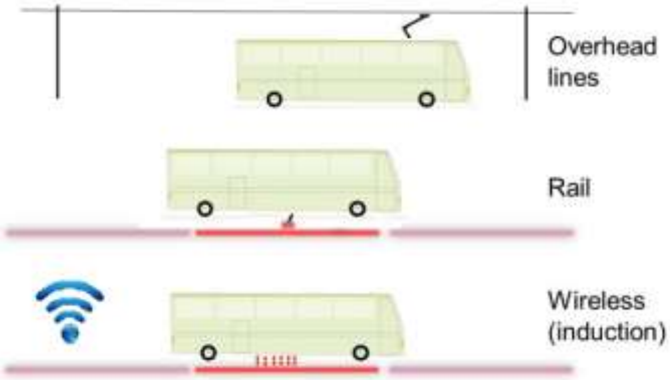

Fig.2. The three main concepts for road ERS and energy transfer to moving EBs.

In the ERS, instead of charging the bus by stopping, they can be charged while driving along the road, and instead of a large battery, a battery of about 70 km is used. If the bus is connected to cables suspended above the road, the bus can be automatically disconnected from this cable if necessary, during operation. The battery is activated when it leaves the electric road and then easily reconnects to the line when it returns to the ERS. The bus can be charged via induction, meaning you can have small batteries on buses and not have to stand still to recharge. Induction is a very expensive alternative to build in and maintain. It costs around 1-2.2 million $ to pave an induction road in a rural setting.

A vehicle that uses a future network of electric roads will have a long-range, reduced need for battery which means low cost, and reduced need to stop to charge which means flexibility. The road to electrification will certainly lead to a better and greener future.

The electrified roads of the future will need some form of payment system to charge for infrastructure and energy use. How such payment systems should be designed is currently still undecided and has been explored in some limited studies [8], [13] prior to this study. Payment systems need to be able to handle complex use cases with multiple actors, roles, and commercial relationships. EVs on electrified roads can be treated similarly to road tolls today, but with a supplement for electricity consumption. For a study of toll systems for electrified roads, lessons should also be drawn from existing toll systems for rail traffic. The payment system to be integrated into the vehicle while driving continuously reports location data and time, including vehicle information, and sends this information via mobile network to be processed for tax calculation and payment according to tariffs and price lists. Road tax is a way to finance future maintenance and investment in road infrastructure essential for economic growth. Numerous countries in Europe have implemented different types of systems on roads to generate tax revenue. The basis for collecting road tax is very similar to the information a payment system would need for electrified roads.

E. The investment cost of the ERS

Uncertainty about what electrified roads could cost is significant. In Sweden, some companies assess that in the long run, road-rail feeding could result in an investment cost of approximately $1 million per km. However, this may come across as an exaggerated observation. In Germany, quite high costs are observed for the conductor feeding alternative to the highway. In this study, it has started with the option of conductor feeding from the mains to the highway, which is the most advanced technology today. In the applications and studies, it is stated that the cost of ERS powered from the grid is between 1 and 3 million $ per km in both directions. Therefore, in this study, it is assumed that the cost of two-way roads is $1.6 million per km (see Table 3). A relatively short economic life is assumed for the electrified road, only 15 years. Therefore, the annual maintenance cost is assumed to be small, except for the wear and tear cost incurred when using an electrified road. Any additional costs for the expansion of electrical grids required to ensure that the required electricity reaches the road are beyond the scope of this work. In addition, even if the operation of heavy traffic can be solved with batteries, the capacity in the network will need to be expanded along the highways. In this study, it is assumed that buses should invest in a battery that provides a range of 70-100 km. Table 2 presents the costs of implementing ERS technology for each solution.

F. Earlier studies and projects

Today, there are a limited number of companies that can build in ERSs. The technology developed by the Elways [21] company is based on ground-based conductive charging. The basic cost of investing in an electric road with Elway's technology is estimated at approximately $ 0.5 million per kilometer for both driving directions. Sweden-based company Elonroad's [22] technology relies on a track on the road that feeds batteries in EVs passing by, provided they have a receiver that sticks to the bottom of the vehicle.

An electric road is supplied with electricity from a surrounding power grid, and there is switchgear along the path that forms the boundary between low voltage and medium voltage.

TABLE II
ERS COST COMPARISONS

Type of ERS	Cost (M$ per km)	Maintenance Cost ($per km)
Inductive	2,2	33.000
Conductive Overhead	1,4	16.000
Conductive Rail	0,8	10.000

TABLE III
OVERVIEW OF COMPLETED AND ONGOING VARIOUS ELECTRIFIED ROAD PROJECTS

Name	Reference	Country	Type of ERS	Company	Comments
Tel Aviv	[27]	Israel	Inductive	ElectReon and Dan Bus Company	600 meters of electrified road along a two-kilometer route between Tel Aviv University Railway Station and Klatzkin Terminal in Ramat Aviv
Smartroad Gotland	[5]	Sweden	Inductive	NA	It installed 1.6 km of electric road on a 4.1 km section between the city of Visby and Visby Airport.
EVolution Road	[28]	Sweden	Inductive	Elonroad, University of Lund	One-kilometer-long section of the road will be equipped with electric rails, The total investment is 9M€. It charges a city bus while driving with 150kW
VICTORIA	[29]	Spain	Inductive	Circe	Eight, 80 cm long, 50 kW coils are installed along the 100-meter-long road, in Malaga city
Select	[30]	USA	Inductive	Siemens	The work was done under the direction of the South Coast Air Quality Management District. Consortium with more than 10 universities.
ELinGO	[31]	Norway	Conductive	NA	In 2018, a preliminary study on the electrification of the E39 was carried out
Visby	[32], [33]		Inductive	ElectReon	the first fully operational electric bus utilizing the company's wireless charging infrastructure.
Michigan	[34]	USA	Inductive	Electreon	ERS to pilot on a 1-mile section of road in Detroit first in the United States.
Wave	[35]	USA	Inductive	Wave	A system in the range from 25 kW to 40 kW can be tested using a 20-seat passenger bus
Karlsruhe	[36]	Germany	Inductive	ElectReon	a bus line connecting the new EnBW training center in Karlsruhe's Rhine harbour to the local public transport system hub.
Brebemi	[37]	Italy	Inductive	ElectReon	The Brebemi highway in Lombardy, 1km. Iveco Bus E-Way and Fiat 500e tested recharge while driving at around 70 km/h.
FABRIC	[38], [39]	Italy	Inductive	ICCS, ERTICO, TRL, ICCS, KTH	outside Torino city, a 260m test track developed. 25cm, 20-100kW
FABRIC	[39]	France	Inductive	ICCS, ERTICO, TRL, ICCS, KTH	The project will allow relevant experiments associated with dynamic inductive charging use on road in Satory.
e-Road Arlanda	[40]	Sweden	Conductive	Elways	It is completed 1.25 miles of the ERS on a public highway, with plans to expand to other parts of the country.
Milton Keynes	[41]	UK	Inductive	Mitsui and Arup	Line-7 15-mile route, covering two suburbs of Wolverton and Bletchley.
Inter-city highway	[41]	Germany	Inductive	ElectReon	Near Cologne city, the investment is €1.9 million, 100m of ERS
E-highway	[42]	Germany	Conductive	Siemens, SPL Powerlines	The system on the Bundesstraße 462 (B 462) federal highway, a 3.4-kilometer route
OLEV	[43]	South Korea	Inductive	OLEV	a bus line in the city of Gumi, Sejong, and Gumi

Currently, there are many completed or ongoing ERS development projects (OH-Lkw [23], COllERS [24], [25], StratON [26]) around the world. The electric road is a promotional project in Sweden to test a new sustainable alternative for heavy traffic with the potential to replace fossil fuel. In 2016, the world's first electrified road between Sandviken and Kungsgården was inaugurated. The ERS used is conductive electricity transmission over overhead power lines, this technology has long been used and proven for trams. The Swedish Transport Administration is carrying out important studies for electrified roads across the country. Inductive energy transfer is available for part of a bus line in Gothenburg and Södertälje. Consortium members are AB Volvo, Bombardier, Vattenfall, Södertälje municipality, Telge Energi, and Göteborg Energi. For trucks, there is an overhead line built in Gästrikland along a road of approximately 2 km between Storvik and Sandviken, and approximately 1 km of electrified roads between Arlanda and the logistics center in Rosersberg. Consortium members are WSP Analysis and Strategy, Kilenkrysset, Elways, NCC, e-Traction, Arlandastad Holding, Airport City Stockholm, Royal Institute of Technology in Stockholm KTH, Siemens, Scania, Ernst Åkeri. German highways usually have one lane where only trucks travel. For this reason, the overhead line was chosen for the project that did not have a car and truck combination. Overhead power transmission by Siemens in Berlin and California, testing of OLEV's inductive power transmission solution in South Korea and work in the UK are ongoing. Current technical conditions and developments for inductive and conductive ERS technologies are summarized in Table 3.

III. RESEARCH CONTEXT AND LIMITATIONS

This chapter provides a general introduction to how the ERS system for EBs works and which parameters are important to it. It offers the existing technology for EBs and the infrastructure needed to run different types of EBs. Finally, it is followed by a subsection that presents the assumptions used in this study. The assumptions are presented in a numbered list with brief explanations of why they are used.

We like to avoid fossil-fueled energy sources, and rail transport is on the rise. There is approximately 32509 km (42%) of highways and main roads in Turkey (as of December 2022). The transportation sector accounts for about 15% of Turkey's greenhouse gas emissions, and more than three-quarters come from diesel fuel [44]. Some municipalities in Turkey have already started using EBs to help them meet their environmental goals by 2050. Transportation with EBs in Istanbul [45], and Samsun [46] started in 2014, and 2022 respectively. Air quality in Kayseri province is considered one of the biggest sources of CO_2 equivalent gases emitted by heavy vehicles.

Turkey's vehicle fleet caused around 81 million tons of greenhouse gas emissions in 2020, with about a fifth of emissions coming from road transport [44]. One of the environmental goals of the Ministry of Environment and Climate Change is that greenhouse gas emissions from transport should be reduced by at least 70% compared to 2010, by 2030 at the latest. Turkey also has a shared responsibility with other countries for the global goal of reducing greenhouse gas emissions to zero in the long term, which must be pursued and achieved. How this will be achieved is not yet known, but priority is given to having a fossil fuel-neutral vehicle fleet by 2030. Existing policy tools and measures are not enough to achieve the goal, more must be done. From a sustainability standpoint, it is absolutely critical that the transition to EVs takes place on time while maintaining flexibility for future systems and that transaction costs are as low as possible. The development of electric transport systems is clear, but how energy is provided or transported in the vehicle is still unclear. Although there are various solutions and variations on this subject with different applications, the ability to bring technology development solutions to the market will provide the main benefit. Although many governments around the world, especially the European ones, have developed projects, no investment has been made in any projects about the electric road in Turkey yet.

A. Energy requirements for EBs

Estimated energy consumption for EBs varies between available articles [34], [47], [48]. Energy use depends on many different parameters such as passenger load, topography, driver behavior, road quality, and climate. Therefore, the energy consumption in Kayseri will vary according to the season. In this study, it is assumed that the municipal buses used in Kayseri city are 12 meters long. Currently, the fuel type and the number of used buses is CNG (Natural Gas) and diesel, 253 and 360, respectively [49]. A reasonable assumption is that such a bus draws around 1.5 kWh/km. If the bus is equipped with a heat pump for cold seasons, it is assumed that about 0.5 kWh/km is used for the heating system and used for days with temperatures as low as 7°C. It is assumed that the locations of the stops are located at a distance of approximately 350 m from each other.

B. Ranges and battery sizes

Since different charging strategies have different requirements for how far the buses have to travel, different battery sizes are provided depending on the charging strategy applied to EBs. It is assumed that the depot-charged buses have large batteries (battery capacity of about 420 kWh). Batteries should never be completely discharged. State of charge (SOC) is an expression of how much of the energy stored in the battery can be reused before the battery needs to be charged. In Table 4, it is assumed that the SOC value of battery-powered buses is 70%.

The ambient temperature in Kayseri varies between –32°C and +40°C, under cold climate conditions, it directly affects the capacity of the battery and this causes the vehicle's range to be shortened. For this reason, it is more advantageous to use a small battery in the EB and supply energy from the ERS.

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TABLE IV
ASSUMPTIONS FOR CALCULATIONS

Parameter	Assumed Value
Energy consumption standard 12 meters bus	1.5 kWh/km
	also approx. 0.5 kWh/km for the heating system
SOC (State of Charge) range - end-stop charged buses	50%
SOC (State of Charge) range - depot-charged buses	75%
Battery Size - Terminal charged buses	200 km
Battery size - Depot-charged buses	400 km
Battery size - Plug-in charged buses	200 km
Battery size - ERS	70 km

C. Annual costs and Cost calculation

The purchase price of the EB is higher than the conventional bus, in this study it is assumed that the price of a 12m EB and a fossil fuel bus is approximately $362.000 and $181.000, respectively. If the battery price is not taken into account, the difference in the purchase price between the Pantograph-charged bus and the depot-charged bus is negligible.

The annual cost of an EB is higher than a diesel bus, but from a socio-economic point of view when noise and air pollution are valued, EBs are profitable. In addition, EBs have significantly lower energy costs due to the more energy-efficient use of electric motors and the fuel price. The current fuel price per kilometer cost for EBs is assumed to be $0.18 (2 kWh/km). The costs for a community bus are summarized in Table 5.

Battery EBs can lead to high driver costs as they have a limited range and possibly cannot operate continuously throughout the 24-hour service and will have to return to the depot to change buses at some point in the day. An assumption of 0.25$/km and 388.725 kilometers traveled gives an assumption of $97.182 total. Important items of the total cost are vehicle purchases, battery, and maintenance costs. Battery sizes can be optimized to reduce costs. Unfortunately, it is not clear how long the infrastructure can be used, as charging technology is currently relatively young.

D. Heating system in the bus

An ICE-powered bus heats the cabin with excess heat from the engine, but an EB that needs cabin heating will use most of the electrical energy pushing it forward. Air source heat pumps can be used to regulate the energy use of the bus air conditioning system up to outside temperatures of around 7°C or less.

E. The bus depot in Kayseri

At the Kayseri bus depot, many of the buses are parked outdoors, without a roof. EVs have a battery thermal management system to keep the battery pack between optimum operating temperatures in hot and cold climates. However, when the vehicle is parked, extreme weather conditions can also affect the battery life. Years are not the only thing that ages a battery. While time is the main cause of deterioration for electric vehicle batteries, the state of charge of the battery and exposure to extreme weather conditions also significantly affect battery life. Figure 3 shows the parking area of the bus depot from Google Maps.

TABLE V
ASSUMPTIONS FOR COST CALCULATION

EB Consumption	EB type	12 meters	0,8-1,6 kWh/km
		18 meters	1,9-3,0 kWh/km
Bus Cost (ICE)	181.000 $		
Electric bus cost	362.000 $		
Diesel Consumption	30 liter /km (in the city)		
Maintenance Cost	0.3 $/km		
Battery size	Big battery: 300 kWh		
	Small battery: 120kWh		
Range	Big battery: 200 km		
	Small battery: 70km		
Maintain charger	3% of investment ($/year)		
Cost battery	150 $/kWh		
Fuel cost	0.09 $/kWh (1.6TL/kWh)		
Fuel cost	1.22 $/liter (23TL/liter)		
Number of runs	388.725 km/year		
Battery lifetime	5 years		
ERS lifetime	15 years		

Fig.3. A bird's-eye view of the existing bus depot in Kayseri.

F. The terrain of Kayseri city

The terrain of Kayseri is hilly in some places. Too much uphill driving will shorten the range of the buses. Fluctuations in topology can have a huge impact on the range performance of EBs. The city is not very hilly although there are some elevations, the topography was studied using Google Earth. Figure 4 shows the city bus routes' from Anafartalar to Ebic Dadagi in Kayseri on a map.

G. Diesel Fuel Price

In order to predict the price of diesel in 2030, we need to make assumptions about how the price of fossil diesel will develop by then. In the first quarter of 2023, the taxed diesel price was $1.2 (23TL) per liter. Global warming, the coronavirus epidemic, and the Russia-Ukraine war have led to an increase in fuel prices. The industry remains uncertain about the future market for diesel fuels, as some European states have passed a law banning the sale of new petrol and diesel cars in 2030. A comprehensive study is needed to achieve the ban on diesel vehicles, it is not yet clear whether the investments will be realized. Therefore, it is assumed that in 2030 the diesel price will be $2 per liter including all taxes.

IV. Methodology and Data Gathering

This section describes the research process, research design, and what methods were used to collect data. It also describes reliability and validity, and how these were taken into account in the study process.

A. Description of Possible Pilot Route

Line R40 runs in both directions, so the graph in Figure 4 should read left to right when looking at the route from Anafartalar to Ebic Dadagi. The route is 35.5 km long and the average value of the land slope is %4. The route has 73 stops and shown in Figure 4 shows that it will be implemented by the ERS infrastructure. Figure 5 shows the topography of the R40 bus line.

B. Choice of Technology

For electric cars, the unit kWh is often used to describe the capacity of the electric car battery, that is, how much electrical energy can be stored, and a capacity of about 40 kWh is common. With a 40-kWh battery of which 90% is available, and with a consumption of 0.17 kWh/km, the range is roughly 210 km. In EVs, the battery is the most expensive component, making them generally more expensive than fuel cars. Electric cars are expected to get cheaper as the cost of batteries for electric cars falls [50]. The price of lithium-ion batteries for EVs dropped from around $1000 per kWh in 2010 to just over $200 per kWh for battery packs in 2016 and continues to fall. By the year 2030, the price is estimated to be able to drop to $100 per kWh [50]. The distribution of electrified road distances, battery size, and the lifetime of the batteries are closely linked. In the absence of an electrified road, large batteries are needed, partly to extend the range and at the same time preserve the life of the batteries. The more electric distances it travels, the more the vehicle can be charged during the journey, meaning the batteries do not have to be the same size. At the same time, the life of the batteries can be increased by a higher percentage of electric trips.

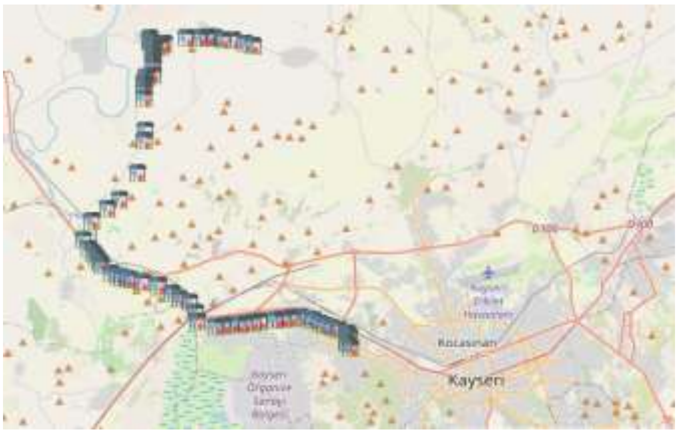

Fig.4. Selected bus route

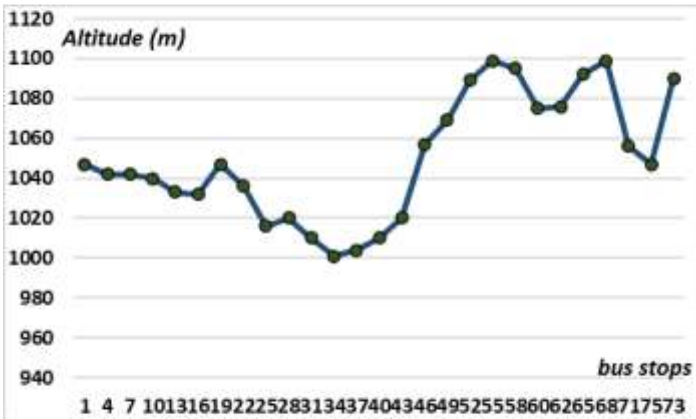

Fig.5. Topography for the R40 bus line. Source: Google Earth.

C. Calculations

This subsection presents the equations used to determine the concluding part; ERS costs, fees, savings, and estimates presented in a bulleted list. Then, the equations used to determine the cost of EB and ERS components are shown and concluded.

- ERS Costs

$$\sum TC_{ERS} = l_r . c_{ers/km} \tag{1}$$

Where;
TC_{ERS} – total cost of implementing ERS ($);
l_r – length of the road (km);
$c_{ers/km}$ – the cost per km ($/km).

- Charge Cost

$$\sum TC_{el} = l_r . c_{el/km} \tag{2}$$

Where;
TC_{el} – the total electricity cost ($);
$c_{el/km}$ – the electricity cost per km ($).

- User fee

$$U_{fee} = l_r^t . u_{fee/km} \tag{3}$$

Where;

U_{fee} – the user fee ($);
l_r^t – the total driven distance (km);
$u_{fee/km}$ – the cost per km of using the ERS ($).

- Forecasts of diesel price

$$P_{in}^{diesel} = \frac{Pd_{2023}}{Pd_{2030}}^{\frac{1}{2030-2023}} \quad (4)$$

Where;
P_{in}^{diesel}– annual average increase of diesel in Turkey;
Pd_{2023} – diesel price in 2023;
Pd_{2030} – diesel price in 2030.

- Received and consumed energy

$$E_{cns} = t/60 . E_{km} . l_r^t \quad (5)$$

Where;
E_{cns} – the amount of electricity received;
t – spent time on ERS (minute);
E_{km}– energy use (kWh/km);
l_r^t – the total driven distance (km).

- Fuel Costs

$$C_f = l_r^d . E_{km} . c_f . 365 \quad (6)$$

Where;
C_f – the annual cost for energy consumption;
l_r^d – the daily driven distance (km);
E_{km} – energy use (kWh/km);
c_f – fuel cost.

- Battery Cost

$$C_{bat} = S_{bat} . c_{kW} \quad (7)$$

Where;
C_{bat} – cost of the battery ($);
S_{bat} – battery capacity;
c_{kW} – cost of energy ($/kWh).

- Energy receiver Cost

$$C_{rec} = c_{rec} . n \quad (8)$$

Where;
C_{rec} – total cost of the receiver;
c_{rec}– cost for one receiver;
n – number of required receivers.

- Lifetime Cost

$$C_{lf} = C_{bus} + \left(n_y\left(C_{OM} + C_f\right)\right) \quad (9)$$

Where;
C_{lf} – lifetime cost;
C_{bus} – cost of the bus;
n_y – number of years;
C_{OM} – operation and maintenance cost;
C_f – fuel cost.

V. Results

This section consists of two subsections: calculations and findings. The first part of this chapter shows the results of calculations using the formulas in subsection 3.4. The second section presents the findings. In calculations, it is done to calculate the distance of the road to be electrified per kilometer. Some first comments:

1. The initial investment is equal to the construction cost of the ERS.
2. Annual savings are savings in operating costs of vehicles. Using EBs instead of fuel saves money. Both the annual savings and the annual cost are calculated according to the alternative fuel vehicle.
3. The total annual cost is the additional cost of buying an EB instead of a fuel bus. The additional cost for buses is assumed to be the same as the battery cost. It is assumed that an EB with a 120-kWh battery has the same price as a diesel bus. It's still a rather cautious assumption, given the estimates that an EB with a range of 70km would already be as cheap as fuel buses.
4. The second part of the annual cost is the maintenance cost of the ERS. It is accepted as 1% or 10.000$/km of the annual investment cost (see Table 2).

In the sensitivity analysis, the effect of EBs needs to have a larger battery will be analyzed in order to make a correct calculation with an infrastructure alternative in the electrification of the road. This reduces the investment cost of the electric road while increasing the capital cost of the buses for the batteries. Boya [51] states that a 175-kWh battery will allow a range of 100 km. They state that the cost of such a battery was €60,000 in 2015. They estimate the cost will drop to €25,000 in 2025 and €19,000 in 2030. Therefore, this study assumes that the additional cost of upgrading the battery (120kWh) to cover 70 km will be €13,300 in 2030.

The expenses of adopting ERS in Kayseri city are discussed in this subsection, along with a cost comparison of the three ERS technologies—conductive rail, conductive overhead, and inductive. The bus route road is 35.5 km long and the cost of implementing ERS (one way) and maintenance cost are summarized in Table 6 varies between the different ERS technologies (see Figure 6).

TABLE VI
INSTALLATION AND MAINTENANCE COST FOR SELECTED BUS ROUTE

Type of ERS	ERS Cost (M$)	Maintenance Cost (M$)
Inductive	78,1	1,2
Conductive Overhead	49,7	0,6
Conductive Rail	28,4	0,4

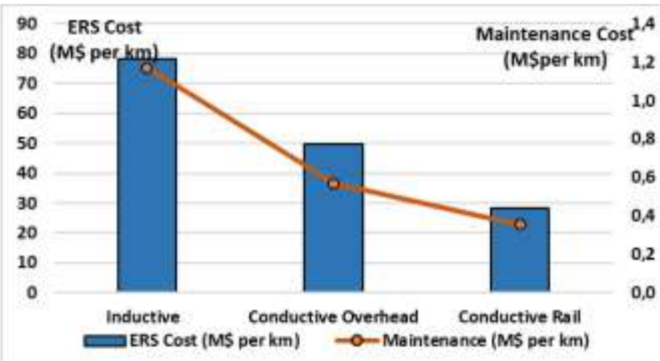

Fig.6. Total investment and maintenance cost to install 35.5 km of ERS.

A standard bus (12 meters) costs about 181.000$ while an EB cost about 362.000$ [52]. The maintenance cost varies between diesel and EBs. The maintenance cost of a diesel bus is about 15.000$ per year and the maintenance cost of an EB is about 5000$ per year. Table 7 compares for the cost of the ICE bus and EB.

TABLE VII
COMPARISON FOR COST OF ICE BUS AND EB

Bus Type	Bust Cost ($)	The maintenance cost for 10 years ($)	The fuel cost for 10 years ($)	Total Cost ($)
Diesel	81.000	150.000	1.422.734	1.753.734
Electric Bus	362.000	50.000	524.779	936.779

The total cost difference between EBs and diesel buses is 816.955$. If society stops spending money at the individual level on bigger batteries and instead spends money collectively on electric road infrastructure, a small battery and an electrified road infrastructure can cost less than a larger long-range battery. If decision-makers stop spending money on bigger batteries and instead spend money on ERS infrastructure collectively, a small battery and electrified road infrastructure could cost less than a larger long-range battery. However, these figures are relatively small when compared to battery and bus costs; with an average of 2023 prices, it will be possible to establish ERS in Kayseri with a 10-year EB cost. Figure 7 shows the costs of the ICE bus and EB in ERS.

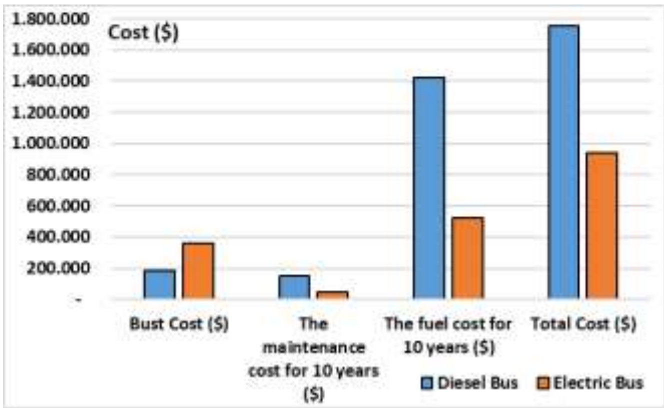

Fig.7. Cost comparison for diesel bus and EB

VI. CONCLUSION AND RECOMMENDATIONS FOR FURTHER WORK

This final section provides answers to the research questions. This section also includes discussions about limitations, research contributions, and some suggestions for future work.

The purpose of this work was to investigate whether roads can be developed and made smarter to promote greener. The main idea of electric road systems is to reduce CO_2 emissions, reduce the dependence of heavy vehicles on fossil fuels, provide good transportation for commercial purposes in the fossil-free society of the future, and at the same time reduce vehicle costs by reducing the battery size needed in EVs.

In this study, the ERS scenario developed for the R40 bus line in the province of Kayseri is examined from the economic point of view of establishing an electric bus infrastructure with a range of 70 km. The cost of implementing this infrastructure is approximately $28.4 million and the annual operating maintenance cost is approximately $400,000. If a large battery is replaced with a smaller battery for each new bus sold, enough savings will be achieved after 10 years to electrify the 35.5km R40 bus line route in Kayseri.

Whether this study will benefit the future development of electrified road traffic is not difficult to answer at the time of writing this article, as this is the first article written for ERS for public transportation in Turkey. Despite the study's probable limitations, it has found that electrified road infrastructures are more economical under all assumptions than the corresponding battery-electric vehicle scenario. Additionally, smaller battery EVs are more affordable than larger battery EVs when combined with ERS. It can be concluded that by reducing battery deterioration and energy consumption, buses perform better when an ERS is installed.

If the ERS is to be expanded and used in Turkey in the future, government architecture, design, and design goals should also be followed. The government should also actively support the development of the design field in Turkey with exemplary actions from the public project. This must be done to strengthen the quality of the designed living environment. In addition, it is something that slows down the process a bit in our day of bureaucracy and decision-making. A design proposal that fits the technology's potential and sustainable intentions could accelerate the development of a fossil-free Turkey.

Whatever the choice of technology for power transmission, electricity routes to commercial operation will need payment systems to charge for infrastructure and energy use. This could be explored in future studies.

Placing solar panels on the road; asphalt road is unused land, instead of installing solar panels on the side of the road or directly on the road, solar panels can be placed on the carriageway. Driving on a shaded road has its advantages; tires provide a lower operating temperature and thus have a longer service life, the car's air conditioning needs to run less on hot days, and road repair costs are lower. This is also because the electricity required for ERS is obtained from solar panels.

REFERENCES

[1] C. Yang, D. McCollum, R. McCarthy, and W. Leighty, “Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California,” Transp. Res. Part D Transp. Environ., vol. 14, no. 3, pp. 147–156, May 2009, doi: 10.1016/j.trd.2008.11.010.

[2] A. Ghosh, “Possibilities and Challenges for the Inclusion of the Electric Vehicle (EV) to Reduce the Carbon Footprint in the Transport Sector: A Review,” Energies, vol. 13, no. 10, p. 2602, May 2020, doi: 10.3390/en13102602.

[3] X. Yuan, L. Li, H. Gou, and T. Dong, "Energy and environmental impact of battery electric vehicle range in China," Appl. Energy, vol. 157, pp. 75–84, Nov. 2015, doi: 10.1016/j.apenergy.2015.08.001.
[4] M.-K. Tran et al., "A Review of Range Extenders in Battery Electric Vehicles: Current Progress and Future Perspectives," World Electr. Veh. J., vol. 12, no. 2, p. 54, Apr. 2021, doi: 10.3390/wevj12020054.
[5] "Wireless electric road charges vehicles as they drive," Smart city Sweden, 2022. https://smartcitysweden.com/best-practice/409/wireless-electric-road-charges-vehicles-as-they-drive/ (accessed Jan. 20, 2023).
[6] M. Gaeta, C. Nsangwe Businge, and A. Gelmini, "Achieving Net Zero Emissions in Italy by 2050: Challenges and Opportunities," Energies, vol. 15, no. 1, p. 46, Dec. 2021, doi: 10.3390/en15010046.
[7] W. Shoman, S. Karlsson, and S. Yeh, "Benefits of an Electric Road System for Battery Electric Vehicles," World Electr. Veh. J., vol. 13, no. 11, p. 197, Oct. 2022, doi: 10.3390/wevj13110197.
[8] H. H. Coban, A. Rehman, and A. Mohamed, "Analyzing the Societal Cost of Electric Roads Compared to Batteries and Oil for All Forms of Road Transport," Energies, vol. 15, no. 5, Mar. 2022, doi: 10.3390/en15051925.
[9] H. H. Coban and W. Lewicki, "Daily Electricity Demand Assessment on The Example of The Turkish Road Transport System-A Case Study of The Development of Electromobility on Highways," Transp. Geogr. Pap. PGS, vol. 2022, no. 2, pp. 52–62, doi: 10.4467/2543859XPKG.22.011.16269.
[10] S. Eslami, Y. Noorollahi, M. Marzband, and A. Anvari-Moghaddam, "District heating planning with focus on solar energy and heat pump using GIS and the supervised learning method: Case study of Gaziantep, Turkey," Energy Convers. Manag., vol. 269, p. 116131, Oct. 2022, doi: 10.1016/j.enconman.2022.116131.
[11] J. Schulte and H. Ny, "Electric road systems: Strategic stepping stone on the way towards sustainable freight transport?," Sustain., vol. 10, no. 4, 2018, doi: 10.3390/su10041148.
[12] D. Jelica, M. Taljegard, L. Thorson, and F. Johnsson, "Hourly electricity demand from an electric road system – A Swedish case study," Appl. Energy, vol. 228, no. June, pp. 141–148, 2018, doi: 10.1016/j.apenergy.2018.06.047.
[13] S. Tongur and H. Sundelin, "The electric road system transition from a system to a system-of-systems," in 2016 Asian Conference on Energy, Power and Transportation Electrification (ACEPT), Oct. 2016, pp. 1–8, doi: 10.1109/ACEPT.2016.7811529.
[14] R. C. Majhi, P. Ranjitkar, and M. Sheng, "Assessment of dynamic wireless charging based electric road system: A case study of Auckland motorway," Sustain. Cities Soc., vol. 84, p. 104039, Sep. 2022, doi: 10.1016/j.scs.2022.104039.
[15] R. Kühne, "Electric buses – An energy efficient urban transportation means," Energy, vol. 35, no. 12, pp. 4510–4513, Dec. 2010, doi: 10.1016/j.energy.2010.09.055.
[16] M. Duan, G. Qi, W. Guan, C. Lu, and C. Gong, "Reforming mixed operation schedule for electric buses and traditional fuel buses by an optimal framework," IET Intell. Transp. Syst., vol. 15, no. 10, pp. 1287–1303, Oct. 2021, doi: 10.1049/itr2.12098.
[17] B. Verbrugge, M. M. Hasan, H. Rasool, T. Geury, M. El Baghdadi, and O. Hegazy, "Smart Integration of Electric Buses in Cities: A Technological Review," Sustainability, vol. 13, no. 21, p. 12189, Nov. 2021, doi: 10.3390/su132112189.
[18] Z. Bi, L. Song, R. De Kleine, C. C. Mi, and G. A. Keoleian, "Plug-in vs. wireless charging: Life cycle energy and greenhouse gas emissions for an electric bus system," Appl. Energy, vol. 146, pp. 11–19, May 2015, doi: 10.1016/j.apenergy.2015.02.031.
[19] B. Csonka, "Optimization of Static and Dynamic Charging Infrastructure for Electric Buses," Energies, vol. 14, no. 12, p. 3516, Jun. 2021, doi: 10.3390/en14123516.
[20] N. Jones, "More than a billion cars to hit the road," Nature, Nov. 2006, doi: 10.1038/news061113-15.
[21] H. Sundelin, M. G. H. Gustavsson, and S. Tongur, "The maturity of electric road systems," 2016 Int. Conf. Electr. Syst. Aircraft, Railw. Sh. Propuls. Road Veh. Int. Transp. Electrif. Conf. ESARS-ITEC 2016, 2016, doi: 10.1109/ESARS-ITEC.2016.7841380.
[22] H. Alfredsson and E. von Essen, "Cost optimized electrification of Lund city bus traffic using Elonroad electric road system," Lund University, 2018.
[23] "Roadmap for an overhead catenary system for trucks," 2022. https://www.ifeu.de/en/project/roadmap-for-an-overhead-catenary-system-for-trucks/ (accessed Jan. 20, 2023).
[24] "International Research Collaboration on Electric Road Systems II (CollERS2)," Electric-road-systems, 2022. https://electric-road-systems.eu/e-r-systems/ (accessed Jan. 20, 2023).
[25] Sundelin Håkan, "Swedish-German research collaboration on Electric Road Systems," Heidelberg, Mar. 2021. Accessed: Jan. 20, 2023. [Online]. Available: https://policycommons.net/artifacts/1966846/swedish-german-research-collaboration-on-electric-road-systems/2718611/.
[26] E. Berlin et al., "StratON Bewertung und Einführungsstrategien für oberleitungsgebundene schwere Nutzfahrzeuge," 2020. Accessed: Jan. 20, 2023. [Online]. Available: https://www.oeko.de/fileadmin/oekodoc/StratON-O-Lkw-Endbericht.pdf.
[27] Sarah Wray, "Tel Aviv pilots 'electric road' to charge buses," Cities-today, Aug. 23, 2020. https://cities-today.com/tel-aviv-pilots-electric-road-to-charge-buses/ (accessed Jan. 20, 2023).
[28] Bernhardt Jens, "Electric road for ebus charging on test in Lund/Sweden," Nov. 28, 2019.
[29] Y. J. Jang, "Survey of the operation and system study on wireless charging electric vehicle systems," Transp. Res. Part C Emerg. Technol., vol. 95, pp. 844–866, Oct. 2018, doi: 10.1016/j.trc.2018.04.006.
[30] "Siemens demonstrates first eHighway system in the U.S.," Siemens, Nov. 08, 217AD. https://press.siemens.com/global/en/pressrelease/siemens-demonstrates-first-ehighway-system-us (accessed Jan. 20, 2023).
[31] Rise Torun and Nørbech Tom, "ELinGO - Electrification of heavy freight transport," Sintef, 2022. https://www.sintef.no/projectweb/elingo/english/ (accessed Jan. 20, 2023).
[32] Powerelectronicsnews, "Electric Bus Utilizing Wireless Electric Road," Oct. 20, 2021. https://www.powerelectronicsnews.com/electric-bus-utilizing-wireless-electric-road/ (accessed Jan. 20, 2023).
[33] Otilia Drăgan, "An e-Bus Starts Testing World's First Wireless Electric Road, in Breakthrough Project," Autoevolution, Oct. 20, 2021. https://www.autoevolution.com/news/an-e-bus-starts-testing-worlds-first-wireless-electric-road-in-breakthrough-project-172164.html (accessed Jan. 20, 2023).
[34] H. Basma, C. Mansour, M. Haddad, M. Nemer, and P. Stabat, "Energy consumption and battery sizing for different types of electric bus service," Energy, vol. 239, p. 122454, Jan. 2022, doi: 10.1016/j.energy.2021.122454.
[35] "Leading the Wireless WAVE," 2022. https://waveipt.com/ (accessed Jan. 20, 2023).
[36] "Wireless electric charging infrastructure for German roads," Electreon, 2023. https://electreon.com/projects/karlsruhe (accessed Jan. 20, 2023).
[37] Nepori Andrea, "Italian highway recharges electric vehicles as they go," Domus, Jun. 21, 2022.
[38] Jitchotvisut Janaki, "Italy's Inductive Highway Project Going Very Well, Says Stellantis," Motor1, Jun. 20, 2022.
[39] "Fabric Project Paves the Way for Large Scale Deployment of Electromobility," Ertico, Mar. 17, 2014. https://erticonetwork.com/fabric-project-paves-the-way-for-large-scale-deployment-of-electromobility/ (accessed Jan. 20, 2023).
[40] "e-Road Arlanda, Stockholm," Elways, 2022. https://elways.se/elways/projects/ (accessed Jan. 20, 2023).
[41] "Developing a functional viable solution for dynamic charging," Electreon, 2022. https://electreon.com/projects/echarge-bast (accessed Jan. 20, 2023).
[42] "eHighway – Electrification of road freight transport," Siemens, 2022. https://www.mobility.siemens.com/global/en/portfolio/road/ehighway.html (accessed Jan. 20, 2023).
[43] S. Lee, J. Huh, C. Park, N. S. Choi, G. H. Cho, and C. T. Rim, "On-Line Electric Vehicle using inductive power transfer system," 2010 IEEE Energy Convers. Congr. Expo. ECCE 2010 - Proc., pp. 1598–1601, 2010, doi: 10.1109/ECCE.2010.5618092.

[44] "Turkey, National Inventory Report (NIR)," Apr. 2022. Accessed: Jan. 20, 2023. [Online]. Available: https://unfccc.int/documents/461926.

[45] Temizer Murat, "Turkey's first electric bus hits the roads," Istanbul, Dec. 2014. Accessed: Jan. 20, 2023. [Online]. Available: https://www.aa.com.tr/en/energy/regulation/turkeys-first-electric-bus-hits-the-roads/12483.

[46] "Turkey's First Ultra-Charging Electric Buses Started Carrying Passengers," Samsun, Aug. 2022. Accessed: Jan. 20, 2023. [Online]. Available: https://www.raillynews.com/2022/08/Turkey%27s-first-ultra-chargeable-electric-buses-started-to-carry-passengers/.

[47] A. S. Al-Ogaili et al., "Review of the Estimation Methods of Energy Consumption for Battery Electric Buses," Energies, vol. 14, no. 22, p. 7578, Nov. 2021, doi: 10.3390/en14227578.

[48] J. A. Manzolli, J. P. Trovão, and C. H. Antunes, "A review of electric bus vehicles research topics – Methods and trends," Renew. Sustain. Energy Rev., vol. 159, p. 112211, May 2022, doi: 10.1016/j.rser.2022.112211.

[49] "Kayseri Ulasim," 2023, Accessed: Jan. 20, 2023. [Online]. Available: https://www.kayseriulasim.com/tr/FaaliyetAlanlarimiz/otobus-isletmesi/hakkinda#:~:text=Kayseri Ulaşım A.Ş'nin,yönetiminde toplam 613 otobüs mevcuttur.

[50] G. Berckmans, M. Messagie, J. Smekens, N. Omar, and L. Vanhaverbeke, "Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030," Energies, vol. 10, no. 9, p. 1314, Sep. 2017, doi: 10.3390/en10091314.

[51] B. Zhou et al., "Real-world performance of battery electric buses and their life-cycle benefits with respect to energy consumption and carbon dioxide emissions," Energy, vol. 96, pp. 603–613, Feb. 2016, doi: 10.1016/j.energy.2015.12.041.

[52] Akgunduz Bilal, "Yerli Elektrikli Otobüs Modelleri, Teknik Özellikleri," Feb. 02, 2022. https://www.dolubatarya.com/haber/yerli-elektrikli-otobus-modelleri-teknik-ozellikleri (accessed Jan. 20, 2023).

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