

# Electrifying Istanbul's Public Bus Fleet: Challenges and Decision Factors

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## ABSTRACT

Public buses play a key role in sustainable urban mobility, and electrification of public buses has recently gained pace around the world as part of achieving net-zero emission targets and decarbonisation efforts. There are challenges, however, in electrifying bus fleets from choosing the right charging technology to adjusting service planning, scheduling and depot management practices. Contextual factors such as climate, topography, financial capacity, government support, etc. also play a key role in understanding and managing these challenges. In this article, Istanbul's bus fleet electrification efforts along with its challenges and barriers are examined. Istanbul's sustainable urban mobility plan (SUMP), issued in 2022, sets out net-zero emission targets as well as bus fleet electrification targets. By analysing Istanbul's current urban mobility in terms of its sustainability in light of this key planning document, the paper discusses key considerations and decision factors for Istanbul's bus fleet electrification.

## 1. Introduction

Cities all around the world have been increasing the pace of decarbonisation and electrification of their public bus fleets. For public bus operators, battery electric buses (BEBs) have now become the most prevalent option for a low-carbon or zero-emission bus fleet among other propulsion technologies (e.g. hydrogen fuel-cell buses, overhead wire electric buses, plug-in hybrid, etc.) as the battery technology has reached maturity. BEBs provide significant benefits such as low or no GHG emissions, energy reduction and low noise, making them an ideal propulsion technology for urban buses [1-2]. Many cities have zero-emission bus fleet targets that facilitate a rapid electrification of bus fleets. For example, the current target date for a zero-emission bus fleet in London is 2034, and

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with additional funding from the government this could be moved forward to 2030 [3]. This means that an average of around 1,000 conventional buses per year would need to be replaced with zero-emission buses to meet the 2030 target. Amsterdam and Copenhagen are planning for a fully zero-emission bus fleet by as early as 2025, and over half of all European capital cities are planning for a fully-zero emission bus fleet by 2040 [4].

Transition to an electric bus fleet requires significant levels of investment and fundamental changes across all aspects of bus operations. All depots will require new electrical infrastructures to be installed, along with other modifications to facilities and the addition of new power supply systems or other fueling infrastructure. Daily operations across depot operations, fleet planning, staff scheduling, vehicle maintenance, road operations, safety and training will have to be transformed. For example, bus electrification also requires a long-term strategy to install electric bus charging infrastructure. In London, electric bus charging infrastructure is being installed at the garages located across London through the installation of opportunity charging facilities, such as pantographs and substations at key locations [3]. Bus garages being prepared to operate electric buses also require essential power upgrades and connection to the national grid and the installation of bus chargers by the bus manufacturer/ technology provider. In most cases, an upgrade to the electricity grid itself is also required.

The acceleration of bus fleet electrification can be achieved through legislation and regulations addressing climate change and decarbonisation. Financial support is crucial for developing cities which may lack the capital to overcome the financial hurdles associated with investing in zero-emission buses. Introducing such initiatives plays a crucial role in accelerating the electrification of public bus fleets in developing cities. Rodrigues and Seixas [5] highlight the importance of new mechanisms for contracting and financing BEBs, policy support from local and national governments, as well as alternative models to facilitate multi-stakeholder approach to infrastructure investment.

Istanbul is the most populous city in both Turkey and Europe with a population of over 15.6 million residents [6]. Although Istanbul can be classified as a developing city, it has a well-developed complex urban transport system, with the provision of multiple modes of public transport (public bus, metro, tram, suburban rail), with extensive walking, cycling, and car use [7]. There are more than 15,800 new vehicles on Istanbul's roads each month representing a year-on-year increase of nearly 80% [8]. According to the GHG Emission measurements in 2019, carried out by the Istanbul Metropolitan Municipality (IMM), transportation (on-road, railway, waterborne) causes 28% of total GHG emissions [9]. On-road transportation causes around 14% of total GHG emissions, being the most significant subsector for the causes of Istanbul's GHG emissions. Diesel oil is the most dominant fuel source of emissions in on-road transportation (11.6 MtCO<sub>2e</sub>) compared to gasoline (1.8 MtCO<sub>2e</sub>) and LPG (830 ktCO<sub>2e</sub>). Private cars and public buses, using conventional propulsion technologies, are the major cause of emissions in the area of on-road transportation. Whereas the public debate is mainly about achieving the conversion of private cars to electric vehicles, electrification of public buses to electric buses presents a significantly higher potential for achieving net-zero targets. In this paper, the focus will be on the potential to electrify public buses in Istanbul, as there are many studies in the literature that address the potential to electrify private cars [10-12]. Section 2 gives an overview of plans that influence the electrification targets and efforts in Istanbul. Section 3 provides a brief history of IETT's - Istanbul's main public bus authority- electrification efforts. Section 4 examines the major barriers to bus fleet electrification in Istanbul. Section 5 discusses the key considerations and decision factors for Istanbul's public bus electrification. Finally, Section 6 concludes the article with further thoughts and recommendations for Istanbul's bus fleet electrification.

## 2. Plans That Influence Electrification Targets and Efforts in Istanbul

In this section, four key planning documents that influence the electrification targets and efforts for Istanbul’s public fleet are presented and discussed. These documents are listed below, ranked by the extent to which they have an impact on the electrification of Istanbul’s public bus fleet.

1. Istanbul Sustainable Urban Mobility Plan (SUMP) (2022)
2. IETT Strategic Plan for 2021 – 2025
3. The Istanbul Climate Change Action Plan (2021)
4. The Twelfth Development Plan for 2024-2028

### 2.1 Istanbul Sustainable Urban Mobility Plan (SUMP) (2022)

One of the nine key objectives set out by Istanbul’s ‘Sustainable Urban Mobility Plan’ [13], issued in 2022, is to have an environmentally sustainable transportation system (Objective-2). This objective provides a guiding policy for the electrification of not only private vehicles, but also public bus vehicles. A list of indicators is developed to measure, monitor, and manage the progress for this policy objective, as shown in Table 1.

**Table 1**  
 Indicators, Baseline Data, and Targets for Objective-2 in Istanbul SUMP [13]

Indicators	Baseline Data	Targets (2040)
Per capita well-to-wheel GHG emissions by all urban area passenger and freight transport modes	GHG = 0.92 tCO <sub>2</sub> eq per capita (2021, Revised Istanbul Climate Action Plan)	60% reduction
Share of electric, hybrid, and hydrogen vehicles used in the public transport fleet	3.59% for Buses – 2020. <i>Rail is electrified already.</i>	100% for buses and rail
Share of electric, hybrid, hydrogen cars and taxis	0.05% of taxis in Istanbul (2020) 0.2% of cars in Turkey	50%
Percentage (%) of population affected by different urban transport noise levels	<55 dBA: 67% 55-59: 12% 60-64: 9% 65-69: 6% 70-74: 3% >75: 0.3%	Total affected over 65 dB decrease by 75%

In addition to the policy objectives and associated indicators and targets as shown above, there are a number of projects, identified as part of the SUMP, that would help transition to the use of zero-emission vehicles, mainly electric, in Istanbul’s public transport system. These projects are

collected under a common theme (Theme-1), namely the ‘Transition to Low Carbon’. The projects that have a direct influence on the electrification of bus fleet in Istanbul are the following:

### *2.1.1 The ‘Low Emission Zones’ project*

This project aims to discourage the use of motorised vehicles in designated zones if these vehicles do not meet emission standards. These vehicles either cannot use the low emission zone, or can only use at a price, based on the ‘polluter pays’ principle. Although the contribution of these low emission zones in emission reduction is limited, it is expected to generate local area benefits as air quality improves. Two areas where LEZ pilot projects are planned to be implemented are, firstly, the Historic Peninsula (Eminönü), and secondly, Kadıköy (Moda District). The project is expected to lead the IETT to prioritise electrifying its bus fleet travelling through these areas.

### *2.1.2 The ‘Decarbonisation of Metrobus (Bus Rapid Transit)’ project*

This project aims to electrify all buses that operate on the Metrobus line, which is the segregated bus rapid transit (BRT) system with 52 km with a daily passenger volume of around 950,000 passengers. Currently, there are 709 buses, all of them diesel, that operate on this line. There are three different brands (AKIA, Mercedes, Otokar) operating four different bus types (AKIA LF25, Mercedes Capacity, Mercedes Conecto G, Otokar Kent XL) on this BRT line [14]. These BRT buses make around 78.4 million km per year, consuming more than 47 million litres of diesel (based on 2023 data). The project aims to prioritise the electrification of buses used in the BRT line due to the significant air quality problems around the BRT corridor, which is located at the busiest urban road of Istanbul, namely D100 Highway, known for its notorious traffic congestion. Associated sub-projects include developing an ‘Electric Vehicle Master Plan by 2050’, building a long-term sustainable plan for incentives/subsidies and investment in electric vehicles, as well as setting realistic targets supported by action plans.

### *2.1.3 The ‘Decarbonisation of the Public Transport Bus Fleet’ project*

This project aims to use only electric and/or hybrid buses instead of using other propulsion technologies such as diesel, CNG, etc. The project acknowledges the fact that the overall contribution of this project to mitigating overall carbon emissions in Istanbul is limited due to the lower share of public buses in the overall urban transport system in Istanbul.

The Istanbul SUMP anticipates that the vehicle fleet in Istanbul will gradually change to electric, irrespective of the projects proposed in the Istanbul SUMP [13], citing the increasing production and sales figures of electric vehicles worldwide. The assumption that worldwide increase in using electric vehicles directly reflected in Istanbul’s transport is misleading, unless the contextual and structural barriers to electrification are thoroughly identified and examined. This assumption also does not factor in whether private electric cars or public electric buses will be prioritised in local and national government’s actions such as tax incentives and other price instruments. Since this area is not considered within the decision-making power of Istanbul Metropolitan Municipality (IMM), it is

understandably excluded from the further analysis of potential barriers to electrification. However, it is imperative to address the wider contextual and structural barriers around electrification to enable the transition to electric buses in the public transport system.

## 2.2 IETT Strategic Plan for 2021 – 2025

IETT's strategic plan for 2021-2025, issued in 2021, recognises the need to electrify the bus fleet, and sets out targets for the annual bus electrification rates (%) until 2025 [15]. According to the electrification target given in this plan, 10% of the bus fleet is foreseen to be converted to electric by 2025 as shown in Figure 1. Given the fact that IETT has currently 3,576 vehicles, a 10% IETT's bus fleet becoming electric means 357 electric vehicles. IETT planned to carry out a feasibility study to better understand the impact of using electric buses. Details on IETT's electrification efforts are given in the next section.

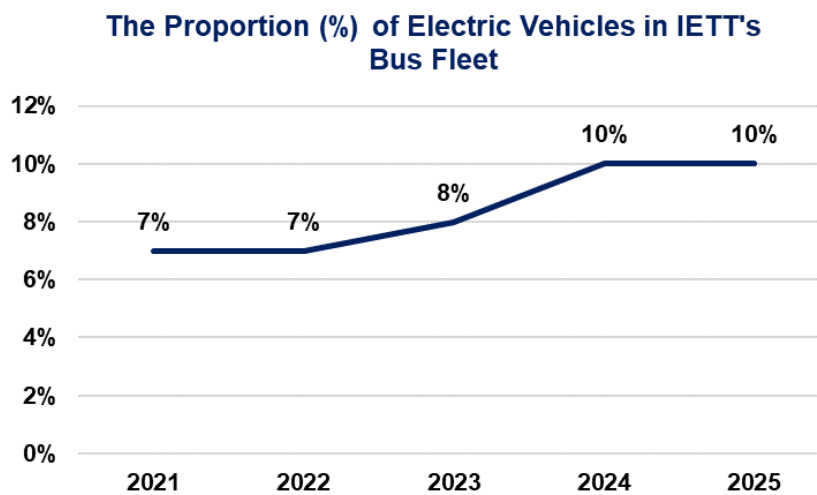


Fig. 1. The Proportion (%) of Electric Vehicles within IETT's Bus Fleet [15]

## 2.3 The 'Istanbul Climate Change Action Plan (2021)'

The Istanbul Climate Change Action Plan (ICCAP) [16] put forward a target date by which Istanbul will be carbon neutral by 2050. As a member of the C40 Cities Climate Leadership Group, the Istanbul Metropolitan Municipality (IMM) signed the Deadline 2020 document in October 2019 and adopted its target to become a carbon neutral city by 2050, also in line with the Paris Agreement goals. The ICCAP sets out how Istanbul will achieve its 2050 carbon neutral goal. The list of actions/strategies as well as targets set for reducing emissions in the area of transport is given in Table 2.

Theme	Strategy	Target	2030	2040	2050
Mode shift - to biking	Increase bicycle use	Proportion journeys by bicycle	1%	5%	
Mode shift - from passenger vehicles	Reduced vehicle use	Passenger automobile use	15%	14%	
		Mini / microbus use	-	1%	
Mode shift – public transport	Shift to public transport	Rate of journeys by Metro	8%	13%	
		Rate of journeys by Light Rail	3%	5%	
		Rate of journeys by Commuter Rail	-	1%	
Passenger vehicle - fuel switch	Electric vehicles and taxis	Electric cars and taxis	65%	80%	100%
	Electrification of trucks Electric motorcycles	Electric trucks	30%	50%	100%
				30%	50%
Passenger vehicle - efficiency	Increasingly efficient vehicles	Improvement in all vehicles' km/litre	8%	14%	20%
Public transport - fuel switch	Electric mini/micro buses	Electric mini / micro bus	100%		
		Electric buses	Electric standard bus	30%	
		Electric BRT	100%		
	Electric commuter rail	Diesel	-	0%	
		Electric	-	100%	
Electric ferry boats	Electric ferry boats	10%	30%	100%	

**Table 2**  
 List of Strategies and Targets for Emission Mitigation in Transport [16]

Targets relating to electric buses are highlighted in blue, and it is interesting to see that whereas there is a target to fully electrify BRT buses by 2030, the target for electric standard buses is to electrify 30% of the total fleet by 2030. IETT is the public bus provider of Istanbul, owning and managing not only its own public buses, but also regulates buses operated by various private bus operations. In a typical day, IETT provides service in at least 800 routes, with around 55,000 trips, carrying around 4 million passengers [17]. As of 2024, IETT has 709 BRT vehicles and 2,697 standard buses [14], and it is also responsible for regulating 3,076 standard buses, operated by private bus operators [18]. Therefore, in terms of standards buses, there is a total of 5,773 standard buses to be electrified in Istanbul, and there needs to be a phased approach to electrify these buses in line with targets set out in the ICCAP.

#### *2.4 The Twelfth Development Plan for 2024-2028*

The Twelfth Development Plan for 2024-2028, set out by the Directorate of Strategy and Budgeting, a national agency under the Presidency of Turkey, recognises the need to transition to electric buses within urban public transport [19]. One of the key objectives in this plan (Objective 496.6) is to expand the use of electric buses. Although the plan does not set out milestones for electrification targets in urban public transport, it refers to the national 2053 target for net zero emission target. This allows some leeway for local governments to set out their own electrification targets considering the local factors such as available resources, market conditions, etc. Therefore, the electrification of the public bus fleet in Istanbul is also endorsed by the national development programmes. Although decarbonising transport as an overall aim in public transport is promoted by the national government, this needs to be supported with a more concrete action plan for assisting local governments financially to achieve this transition.

### **3. IETT's Electrification Efforts**

IETT started electrifying its fleet in 2019, with the introduction of electric vehicles (electric cars and electric shuttles) in the Princess' Islands, which replaced horse-drawn carriages. Although it led to some negative reaction by the residents of these Islands due to concerns over vehicle sizes, BEB operations on the Islands have contributed to IETT's experience of operating BEBs. In 2024, there are 170 electric vehicles in IETT's bus fleet as listed in Table 3.

**Table 3**

IETT Electric Vehicle Fleet [14]

Vehicle Type	Units	Procurement Year	Passenger Capacity
Green Car LSV 4	20	2019	4 passengers
Green Car Shuttle 14	40	2020	14 passengers
SGMS MASTIFF M4	60	2020	4 passengers
CLEANVAC Emicgro	50	2023	4 passengers

It is noteworthy that all these electric vehicles operate in the Princess' Islands, and there is not any electric bus operating yet in the mainland Istanbul except the converted test bus explained below. IETT has plans to purchase 100 standard electric buses by the end of 2024, to be operated in the BRT line. However, there is still a need to set out a phased procurement plan to electrify the bus fleet, not only for IETT's own public buses, but also private operators' buses regulated and managed by IETT.

IETT has also been carrying out tests for electric buses recently [20-21]. IETT also started its programme to convert its current diesel buses to electric buses [22]. In cooperation with ISBAK, which is a subsidiary municipal company providing smart and intelligent systems and software solutions for the activities of IMM, IETT converted a diesel bus, purchased in 2006, into an electric bus. Whereas the diesel bus used to consume 45 litres of diesel for a 100 km trip before the conversion, after the conversion it only consumes 100 kWh electricity power for the same distance, showing the potential energy savings for a larger conversion or electrification of the fleet. A converted bus is calculated to provide a saving of 31,500 litres of diesel in a 100,000 km trip along with associated emission reductions. The converted bus has a range of 250 km and a recharging duration of 1 hour 45 minutes (for the full charge from 0% to 100% state of charge (SoC)). IETT aims to convert at least 10 more diesel buses to electric by the end of 2024.

Although the conversion of diesel buses to electric buses can be regarded as a complementary strategy to contribute to IETT's overall electrification strategy, it needs to be complemented with a long-term phased plan to purchase and replace diesel buses. The priority of electrifying the BRT buses has also its challenges, not limited to financial challenges, that need to be addressed. During peak hours, the frequency of BRT services is 17 seconds, and these buses run around 400 km daily. As a result of these operational constraints, the electrification of BRT buses requires a large number of spare buses due to longer charging and layover times and depot space due to charging infrastructure, which are both currently not adequate.

#### 4. Major Obstacles to Electrification

There are a broad range of obstacles to the large-scale electrification in Istanbul. Among these challenges, 'political and social' and 'financial and economic' barriers stand out most. The decarbonisation of the electricity grid, for example, to allow zero-emission bus fleet requires a coordinated effort on the part of local and national governments. Similarly, IMM is unable to realise a full-scale electrification with its own financial resources only, requiring the financial support of national and international agencies. There are also limitations for IMM to get access to international and private sector finance for climate funding. Currently, there is no financial support mechanism that would incentivise long-term electrification undertaken by local governments or local bus operators [23]. Receiving political and social support for electrification is another key barrier that needs to be addressed. Istanbul's current Sustainable Urban Mobility Plan (SUMP) seeks to provide

a long-term strategy with associated actions for electrification; however, this needs to be complemented with a micro-level electrification strategy and roadmap.

One of the key technical challenges for electrification of bus fleet is the range of BEBs, as their ranges are still considerably shorter than that of diesel buses. This necessitates a new planning approach that would take into account parameters such as route topography, temperature, shorter blocks, and charging management. Furthermore, there are technical areas such as battery use including capacities, charging cycles, and ageing processes that need to be addressed. It can be assumed that battery technology will mature in the coming years, overcoming the range issue in BEBs. This means BEBs will achieve the same range as diesel buses. Since Istanbul's bus routes are much longer than other cities in Turkey and Europe, range will be a major issue to tackle. Besides range concerns, issues around the charging processes are also critical. Charge point occupation, energy costs at peak times, charging curves, and battery health need to be addressed in overall BEB operational management. The next section discusses how these barriers can be overcome in the context of Istanbul.

## **5. Discussion: Key Considerations and Decision Factors for Bus Fleet Electrification in Istanbul**

The first steps for introducing BEBs into a city typically involve developing feasibility studies, assessments, roadmaps, and testing and piloting to understand how BEBs perform locally. A feasibility study should examine the current route network, fleet size, energy demand, and total cost of ownership (TCO) for BEBs. Local traffic, weather conditions, passenger load, the use of air-conditioning, charging efficiency and driving behaviour are the major determinants of BEBs' operational performance as stated by Zhou *et al.* [24]. Understanding each city's unique needs has been crucial to developing an electrification plan that works best for them. In this section, key considerations for Istanbul's full-fleet electrification are discussed.

One of the unique challenges facing bus electrification in Istanbul is that the metropolitan area is quite hilly, which can impact BEB performance. The city's topography needs to be examined thoroughly to identify the most viable routes and corridors for electrification. These corridors and routes should be assessed in terms of the length, slope, demand profile, road conditions, and charging opportunities for each. As argued by Wang *et al.* [25], unstable driver behaviour with greater speed fluctuation or acceleration can also reduce battery efficiency. This could be particularly problematic for Istanbul's fluctuating traffic conditions, that lead to unstable driving speeds throughout the day.

Significant societal benefits of BEBs in the form of decreased noise, reduced emissions, and decreased energy usage along with savings in the total cost of ownership (TCO) are discussed in the literature [26-27]. An equity-centred approach can be adopted to ensure that the bus fleet electrification would benefit the city's most vulnerable populations. In line with Istanbul's proposed 'Low-Emission Zones' project, electrification can prioritise these low-emission districts having higher pollution levels and lower-income populations. Bus fleet electrification can be an opportunity to improve environmental and social equity in the city.

The financing model for electrification is key to ensure long-term electrification. Unlike diesel buses, BEBs are more expensive to purchase, but less expensive to operate and maintain. Mahmoud *et al.* [28] point out that BEBs are capable of meeting the current operational requirements; however, initial investment is still a major barrier to electrification. After the initial steps of planning and trialling BEBs, a financial strategy to support and sustain BEB adoption needs to be set out. Developing financial models to have a better understanding of the total cost of ownership (TOC) of

BEBs, including procurement, infrastructure, operations, maintenance, battery disposal, and financing costs, is essential. When considering a TCO framework for BEBs, higher upfront capital costs need to be balanced with lower operating costs.

Selecting the right charging infrastructure is a key decision factor in electrifying the bus fleet. Battery performance, range, and charging time are key factors in determining how long a BEB can be in service. Selecting the optimum location for charging infrastructure, types of charging (plug-in or pantograph), and charging duration have a major impact on BEB operations. Selecting the right mix of charging infrastructure and locations is a critical step in the electrification of bus fleets. If this is well aligned with the service schedule and route network, it can help lowering the replacement ratio. Xylia *et al.* [29] suggest that lower fuel costs for BEBs can offset the high investment costs in installing charging infrastructure, especially when the availability, efficiency and effectiveness of charging infrastructure are secured. Verbrugge *et al.* [30] recommend undertaking an accurate energy consumption assessment by synchronising opportunity charging and depot charging when transitioning to large bus fleet scheduling. Gao *et al.* [31] suggest that fast charging via frequent short-time opportunity charging at a designated bus stop after completing each run of an assigned route can help reduce the need for longer charging durations that would cause schedule delays. There are also advantages with opportunity charging in terms of its impact on TCO. For example, Basma *et al.* [32] provide a case study from a bus line in Paris where results show that overnight depot charging results in TCO, 13% higher than the TCO with end-of-line opportunity charging. Given the long routes in Istanbul, opportunity charging should be considered as a key part of the overall charging strategy.

Given the financial constraints of Istanbul's bus operations, it is important to achieve as close to a 1:1 replacement of electric to diesel buses as possible. The types of charging infrastructure, number of chargers and stations needed for each type, available space for installing charging stations (in existing depots or along the routes), potential for new depot space, and capacity of the grid should be calculated for the full-scale electrification. Long charging times of BEBs requires a charging scheduling strategy to meet service requirements and energy demand [33]. Charging durations vary from slow-charging mode (e.g., 6 hours) to the fast-charging mode (e.g., 10 minutes) [34]. Assessing different charging strategies should be done in the context of the current service schedule, which informs how many BEBs are needed over which routes. This evaluation should also consider projections of growth and demand, as most infrastructure generally has a planning horizon of 10 to 20 years at a minimum. Dirks *et al.* [35] analysed the impact of battery capacities and charging power on the long-term bus fleet electrification in the city of Aachen, Germany and showed that medium-power charging facilities together with medium-capacity batteries perform higher than networks with low-power or high-power charging facilities.

One of the greatest challenges with regards to the electrification of IETT's bus fleet will be to ensure having sufficient depot space. Irrespective of charging type, depots will need to be retrofitted or constructed anew for BEB infrastructure. Depots should have enough space for charging infrastructure. Depot space needed is dependent on the type of charging mode (overnight plug-in or opportunity overhead). Due to the impact of cold temperature on battery degradation, charging areas need to be sufficiently covered and ventilated, and there needs to be adequate places for heating and cooling electric hardware, considering sensitivity to weather and seasonal fluctuations.

The amount of funding and financing available in Istanbul for electrification will have an impact on the types of charging infrastructure as well as the number of BEBs that Istanbul can afford. Furthermore, the limited knowledge and best practices for charging BEBs (as different cities use different types of charging) makes it harder to have a clear guidance on what works best for different

types of systems and conditions, which is a concern for decision-makers. Searching the available technologies, understanding how they are linked to the service schedule, and understanding financing for charging types is critical.

Whereas BEB contracts and tenders are similar to traditional public bus contracts, there are new stakeholders and contract areas such as charging operators and maintenance to consider for both ownership and operations. The high purchase costs of BEBs necessitates a shift of focus from procurement cost to TCO procurement model as well as new financing schemes. New innovative financing schemes (e.g. battery leasing) can be considered for contract planning, which allows decoupling operating contracts from return on investment. Contracts are part of an interlinked and iterative planning process for electrifying bus fleets. Topal [23] suggests separating the ownership from operation contracts for the bus procurements by IETT. Operational contracts can decrease the financial risk of owning and operating the bus fleet. This separation can allow changing operators when the service quality is inadequate. Contracts should also take into account the potential interoperability needs of multiple BEB models to make sure that the operator is not tied to one manufacturer.

BEBs and lithium batteries have greatly changed the risks related to vehicle fires for firefighters and general population. When a BEB catches fire, it is always quite intense, and heat is sustained when the battery module is involved. BEB fires are always more difficult and complex to put out compared to a vehicle with a combustion engine. BEB fires require a significantly larger volume of water and increased resources and the duration of intervention has increased. It is important to undertake a fire hazard analysis to identify the hazards of BEB fires, gain an understanding of how a BEB burns in different scenarios, and present mitigation strategies. Key measures to tackle safety of BEBs include adjustments in depot layout, bus parking rules, adding quarantine zones and real-time monitoring of batteries with alarm / alert systems. Addressing battery end-of-life management with safe disposal and recycling measures is also key from both safety and environmental perspective. Once a BEB battery reaches its end of useful life, there are three main options: second-life use, recycling, or disposal in a landfill or waste management facility. This issue needs to be considered early in the electrification phase when BEBs are procured and clear terms should be added in the procurement contract.

## **6. Conclusions**

As climate change is accelerating, cities aiming to electrify their bus fleets has also been increasing. However, electrification of bus fleets is still seen as a risky endeavour by many cities, as the transition to full-scale electrification is still at an early stage. This article discussed some key considerations, barriers, and challenges for the electrification of Istanbul's public bus fleet as well as providing key information that could help in decision making for long-term electrification plans.

Electrification of Istanbul's public bus fleet should be seen as part of a wider zero-emission mobility strategy with an aim to create a more sustainable and resilient city. Planners and decision-makers must adopt long-term strategies to improve accessibility, reduce emissions, and increase socioeconomic benefits. Istanbul's Sustainable Urban Mobility Plan (SUMP) is a good first step to promote strategies that encourage zero-emission technology adoption. Creating zero-emission zones in Istanbul as well as decarbonising Istanbul's bus and BRT vehicle fleet, as stated in the SUMP, are projects that the local government can employ to encourage a full-scale BEB adoption. This should be supported with vehicle emission standards, fuel quality regulations, fuel and tax reform, and commitment to procuring zero-emission vehicles. Encouraging modal shifts to more sustainable

modes of transport, including shared mobility, public transport, cycling and walking should be seen as a higher strategy enabling electrification. Electric bus fleets need to be given importance at least as much as electric personal vehicles as BEBs help decrease GHG emissions at a significantly higher rate per passenger than the transition to personal electric vehicles.

Electrification of bus fleet in Istanbul cannot be achieved without decarbonising the electricity production. Given that the energy and electricity production in Istanbul still relies on unclean sources (e.g. coal), there needs to be an encouragement of using renewable and clean sources for energy production. The environmental benefits of electrification can vary depending on the sustainability and cleanliness of the electricity produced by the grid. Therefore, a multi-stakeholder approach needs to be adopted to upgrade grids and transition to clean energy sources.

Electrification of bus fleets provides an opportunity for Istanbul to achieve a more sustainable and liveable city. Istanbul's deteriorating quality of life with unbridled motorisation and urban sprawl makes it imperative to set out policies prioritising sustainable policies. By adopting a full-scale electrification of bus fleet, coupled with wider policies to encourage modal shift to sustainable modes, Istanbul can reduce GHG emissions, improve local air quality as well as enhance the quality of life for its residents. By adopting a wider electrification policy, Istanbul can work towards achieving climate goals in the next decade and beyond.

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### Conflicts of Interest

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