Understanding Electric Bike Adoption in Pakistan: The Role of Economic Benefits, Environmental Concern, and Technology Acceptance

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Abstract: *With the ongoing deterioration of the environment and the soaring fuel prices in Pakistan, there is a need to look for green means of transportation. This study aims to find out the economic and environmental benefits of electric bike (EB) as an alternative vehicle in Pakistan especially in Lahore and Karachi. The study examines factors including perceived usefulness, perceived ease of use, environmental concern, social influence, cost benefit perception, perceived value, trust and electricity accessibility and their influence on consumers' behavioral intention to use eBicycles based on the extended Technology Acceptance Model (TAM). The process of collecting quantitative data was done using a structured questionnaire with a sample of 1000 participants in both cities who were targeted for a cross sectional survey. Structural Equation Modeling (SEM) was used to analyze the data with maximum likelihood estimation. The results show that perceived usefulness, perceived ease of use, social influence, environmental concern, cost benefit perception, perceived value, and trust are significant and positively influences electric bike adoption intention. On the other hand, the finding of negative but insignificant relationship between the electricity accessibility and perceived usefulness was an indicator of infrastructure issues in Pakistan. Overall, the study indicates that the encouragement of e-bike promotion can be achieved by preparing charging stations, financial support by the government, and asserting the environment. The results yield some valuable implications for policy makers, manufacturers and environmental agencies providing incentives for sustainable mobility in developing countries.*

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ISSN: 1755-1978 (print) 1755-1986 (online)

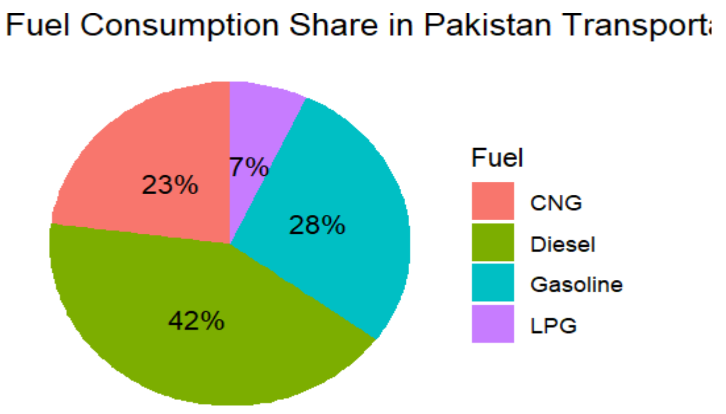
Keywords: Electric bikes; Technology Acceptance Model; Environmental concern; Cost-benefit perception; Sustainable transportation; Pakistan; Lahore; Karachi; Consumer behavior; E-mobility adoption

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has projected that the total emissions need to be reduced by 40–70% by the year 2050 to limit the warming to 2.0°C. The transport sector has experienced the greatest growth in GHG emissions over the last decades, and industrial processes and fossil fuel combustion accounts for about 78% of the emissions worldwide. These emissions are responsible for climate change and are causing disturbing environmental damage (especially in large cities with heavy traffic). Pakistan is one of the countries that is most vulnerable to climate change even though it contributes very little in this respect. The increasing pollution of the transport sector contributes heavily to national carbon emissions, and even deteriorated air quality in the country, as recorded by the Air Quality Index, which is 5 to 10 times higher than the WHO recommendations in our major cities, in 2019." The situation is worsened by the high reliance on fossil fuels and an increasing import bill that is putting strain on Pakistan's economy.

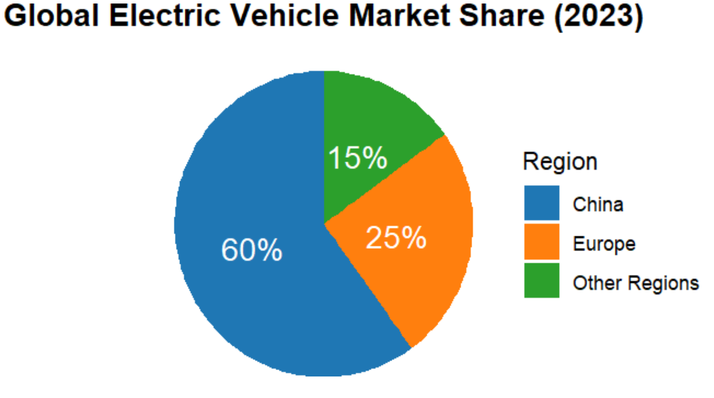
It's equally hard to fathom life today without safe, cheap transportation that contributes to a variety of uses in everyday life. It is mainly dependent on traditional fuels such as gasoline, diesel fuel, CNG, LPG etc, in the transportation markets. The fossil fuels are the most common types of energy used in transportation globally [1]. In the fields of personal mobility, public transport and logistics, commercial delivery and agriculture, conventional fuels are applied in each of these areas [2]. Fossil fuels (gasoline, diesel, CNG and LPG) are heavily relied-upon by developing countries such as India, Pakistan, Afghanistan and Bangladesh for transportation activities both in rural and urban areas [3]. The world is facing a real transport crisis as a result of dwindling of non-renewable sources around the world which contributes to the growing population needs [4].

Pakistan is an oil importing country, a huge portion of the budget is allocated for fuel imports to meet Pakistan's fuel demand. Pakistan purchased 6.6 million tons of oil during July-March (FY-2019) from the international market worth of 3.4 billion USD [5]. Based upon rising global prices, the oil import bill for Pakistan in 2023 is estimated to be around 8.5 billion USD resulting from inflation[6]. The transportation sector in Pakistan consumes approximately 45% of the total amount of fossil fuels, comprising of around 28% gasoline, 42% diesel, 23% CNG and 7% LPG [7]. The inflation rate is also a key variable impacting fuel and consequently all sectors. The transportation, delivery and commuting sectors were significantly affected in Pakistan in 2023, as fuel prices rose 35% and in 2024 a further 52% compared with previous years [8].



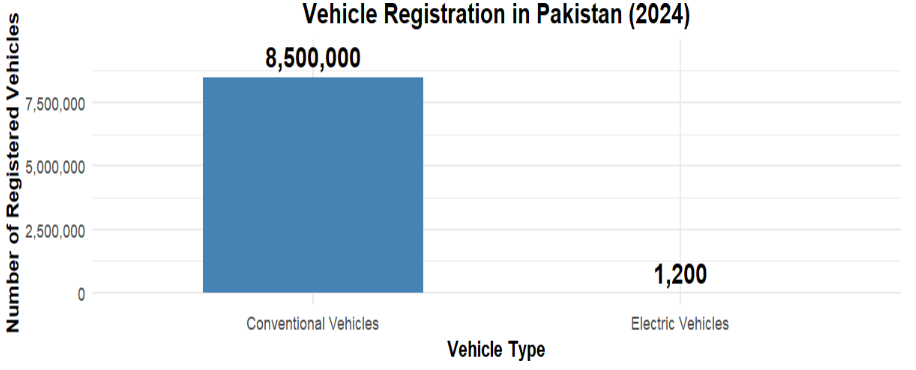
The transportation fuel use pattern for Pakistan is shown in Figure 1, where diesel has dominant share of 42% indicating high consumption in transportation and logistics activities, while gas has a 28% and is mostly consumed in private vehicle transportation and 2-wheelers. This dependency on external energy sources leaves a country economically vulnerable, as evidenced by the cost of oil imports in Pakistan for 2023 of USD 8.5 billion.

Concerning to fuel expense increments and the draining of normal assets of petroleum based fuels, the world is moving towards eco and monetary unwavering frameworks of renewable and option modes of transportation, for example electric vehicles (EV) [9]. In 2023, the worldwide sales of EVs stood at 14 M, accounting for 18% of total car sales, that means EVs from China accounted for 60%, Europe with 25%, and the rest of the world with 15% [10]. Especially, electric bicycles have attracted 42% of the total electric vehicle market in the world with a sales of more than 6 million units sold a year [11]. Pre-installed equipment is used to meet transportation needs efficiently using clean energy technologies [12,59].



The EV market share by region is provided in figure 2, this indicates that China has a major share of the EV market, with 60%, due to its aggressive government policies and expansive charging infrastructure, and Europe has 25% share driven by its sensitivity for the environment. Developing countries, on the other hand, such as Pakistan, continue to significantly lag behind in technology with respect to the adoption of consequences, and it can become a challenge and opportunity for the developing countries to adopt EBs.

Sadly Pakistan has not been able to use advanced technology on large scale for the use alternative fuels for transportation. But in some regions of Pakistan Renewable clean energy transportation projects are attached such as Pakistan has electric bus service, electric motorcycle service and solar powered transportation [13]. As of 2024, Pakistan presently has 1,200 EVs compared to 8.5 million conventional vehicles, which means EVs occupy less than 0.02% of the overall vehicle market. There are only 15 main cities with EV charging stations, namely Islamabad, Lahore and Karachi, and more than 3500 petrol pump stations are working in the country [14].



As shown in figure 3, the ratio of conventional vehicle registration is much higher than that of EVs in Pakistan 8.5 million conventional vehicles to 1,200 EVs indicating a significant opportunity for EB penetration in Pakistan, which is a two-wheeler market.

All of this aside, there is increased mobility by population growth causing greater demand for fuel for transport and higher gas emissions [15]. Amongst the different modes of transport, the number of vehicles in Pakistan has increased by 37% from 6.2 million in 2015 to 8.5 million in 2024 [16]. Pakistan is a developing nation, wherein not proper standards for vehicles and emission labels are defined and implemented. This results in a higher gas emission rate than the limited ones provided by the European Union (EU) and has serious consequences on the environment and human health [17]. About 28 million tons of CO_2 are released in the transportation sector each year in the Pakistan, where the contribution of gasoline vehicles is 48%, diesel vehicles 35%, CNG vehicles 12% and LPG vehicles 5% [18]. The amount of CO_2 emitted by a vehicle on the Pakistani roads is 2.3 times more than the EU limit and particulate matter emission is 3.8 times more than EU limit [19].

Newly analysed literature reveals that the world is evolving toward alternative options in the way of transportation, and is more concerned about gas emissions than economic issues of transportation fuels. According to a review research, electric vehicles are the best alternative for short trips in cities, since they have less brake and gas emissions, and competitive operating cost with conventional vehicles [20]. An e-bike costs around \$0.03/kkm, vs. \$0.12kkm for gasoline and \$0.08kkm for CNG-powered modes of transport – 75% and 62% more economical, respectively [21]. eBikes use 2.5 kWh/100 km whereas, gasoline vehicles use 8.5

liters/100 kms [22]. Similarly, Rajper & Albrecht stated that the energy crisis is the reason that the adoption of EVs is high in the developing countries such as Pakistan and India [23]. By year 2030, Pakistan needs to register and encourage alternative modes of transport such as electric bikes and scooters, which consume 5-10% gasoline [24].

Subsequently, Khan and Bokhari depicted the potential of electric transportation in Pakistan and electricity in comparison with gasoline, indicating that e-bicycles are more cost-effective and environmentally friendly than electricity powered vehicles using gasoline [25]. Purchase price of electric bikes is PKR 120,000 – 180,000 which for gasoline e-bikes is 14-18% less expensive than the comparable PKR 140,000 - 220,000 gasoline powered motorcycles [26]. E-bike battery replacement cost is PKR 35,000 – 50,000 per replacement after every 3-4 years while the cost of maintenance of the engine in case of gasoline motorcycles is approximately PKR 8,000 – 12,000 per year [27]. Cox & Mutel did a comparison of electric motorcycles and other fuels and proposed low-cost and low-gas emission in electric transportation [28]. Hwang also compared electric scooter with other fuels for transportation [29]. They found that electric bikes have low emissions but are of economic benefit as well as higher mileage compared to other fuels. An electric bike will deliver 60-80km/kWh (240-320 km/full charge), while a motorcycle with a gasoline motor will achieve 40-50km/l [30]. Liu reported that gas emissions can be lowered by 15–45% for city commuting via an e-bike [31]. Ebikes do not directly emit any of these pollutants, whereas gas-run motorcycles release 120-150 grams of CO_2 per kilometer. The application of EVs in Pakistan would help to promote sustainable development as Pakistan has a huge potential for renewable energy resources because of its geographical position, Raza reported [32]. Pakistan's solar power potential is estimated to be 60,000 MW, with wind power estimated to be 12,000 MW, which can provide power to 15 million electric bikes each year [33].

But, the studies that are going on in Pakistan and even around the globe is based on alternative transportation fuels for environmental sustainability. According to the above literature search, the world is looking towards Renewable Energy sources, cutting on emission gases, and other transportation modes such as Electric Bikes, Electric Scooters and Electric Vehicles (EVs). However, different modes of transportation, as it concerns the economy, is not nearly discussed enough [34]. Due to the increasing inflation rate and energy crisis day by day, the economics of transportation fuels have a great impact on the economics of a developing country. One of the key problems that need to be solved is for an economically and environmentally viable mode of transport to be put in place for the development of the country [35].The two main departures from the previous studies have been done in the present study as: (1) Empirical quantification of economic and environmental benefits of EBS specifically in the context of Pakistan by employing the current fuel price scenario (2020-2024), and (2) Combining the economic and environment benefits with an extended TAM to get more insights about the drivers for adoption, which has not been done in any previous study in developing country context. Previous research has focused on either environmental benefits OR technology acceptance but this study deviates from this as it focuses on both. With a 6% reduction in transportation fuel imports by using 20% electric bikes for gas motorcycles, Pakistan's savings in fuel imports are around 2.1 billion USD per year [36]. These are significant economic and environmental positive effects, but without converting users to e-bike buying, they don't benefit users at the client end. It is important to have an understanding of what factors influence intention to adopt, as well. A well-established theory for analyzing the technology adoption, the Technology Acceptance Model (TAM), focuses on the individual's perceived usefulness, ease of use and psychological aspects of technology use [60]. But, the main use of TAM has been in developed country settings. The model needs to involve social-economic contexts as a result of the specific situation in Pakistan such as volatile fuel prices, lack of electricity reliability and high inflation. Hence, the economic and environmental argument for adopting EBs is quantified here by secondary data analysis, followed by analysis of psychological and social determinants of EB adoption intention based on an extended TAM leading to combined evidence for policy and practice.

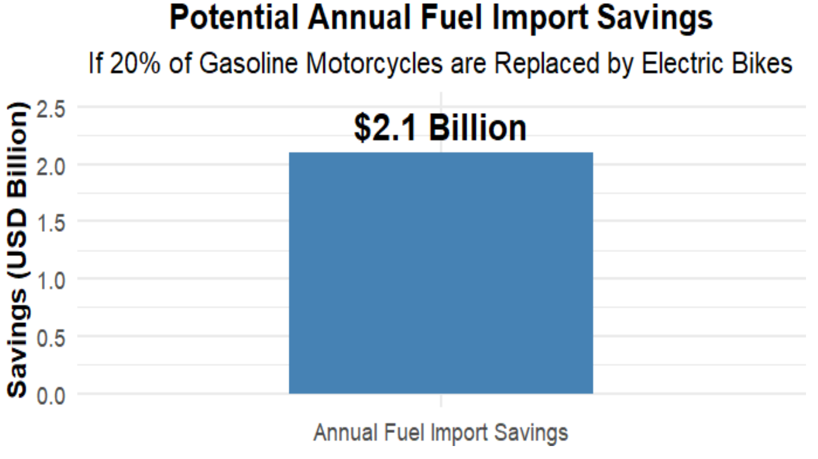


Figure 4 presents a scenario of possible annual fuel import savings from EB adoption, highlighting that a small shift to EB could have big economic benefits.

Hence, the economic and environmental comparison of conventional transportation fuels (gasoline, diesel, CNG, LPG) and electric bike is based on the fuel properties, consumption, availability, performance, operating cost and gas emissions in order to comprehensively assess the benefits of using electric bike as sustainable transportation fuel in Pakistan. The results will be used to generate best practice policy recommendations for policy makers, industry and consumers.

Chapter 2: Research Methodology

2.1 Introduction

A quantitative design is selected for this study to explore perceived economic and environmental advantages of e-bikes as alternative fuel source for conventional means of transport in Pakistan. The research primarily employs data gathered from the urban population of the two major cities, namely Karachi and Lahore, where the issues of transport congestion, fuel prices and environment issues are relevant. They're asked questions on a structured questionnaire from those who have experience with or knowledge of electric bikes and their traditional counterparts. The methodology aims to tap into the perceptions, preferences, and intentions toward electric bike adoption in an urban setting in Pakistan[37].

A survey method is used in this study as it is suitable in measuring the attitudes and perception of a large number of people. Primary data will be used in the research as it is interested in comparing benefits and user evaluation which would reflect the general opinions of potential users in the real world. The reason for selecting Karachi and Lahore is the fact that these are two big metro markets in Pakistan in terms of vehicle and fuel use, and traffic congestion where the need to have sustainable mobility infrastructure is increasing rapidly. This makes them ideal places to try the idea of using eBikes as an alternative transportation option to cars and other modes.

2.2 Purchase Intention

Purchase intention is a state of readiness or willingness to buy or use a particular product or service. In studies on consumer behavior, is an important factor to explain the selection choice to choose an option. Purchase intention, as in the case of e-bikes, represents the level of acceptance and willingness of potential consumers in Karachi and Lahore to use e-bikes as a substitute for fuel-powered modes of transportation.

In the era of increasing fuel prices, traffic congestion and environmental pollution in big cities of Pakistan, purchase intention of e-bike is an important area to study. An understanding of the factors that influence this intention can shed light on how consumers value economic and environmental benefits of electric bicycles. It also acts as valuable information for proponents of sustainable urban mobility for policy and transport planners as well as manufacturers.

2.3. Perceived Ease of Use:

PEU means the extent to which a person believes that the use of a technology or product will be effortless. For electric bikes, it is used to assess how convenient is it to operate, maintain and control the bike including the motor, battery system, riding feature, etc., to the potential users in Karachi and Lahore. When it comes to transport, if users perceive the e-bike as simple and convenient to use, they will be more likely to think of it as a practical transport option[38].

This construct is crucial as ease-of-use frequently influences actual and/or future behavior. Electric bikes: Users are more inclined to use them when they feel they are easy, not too much to learn, and will take less effort from their day-to-day travel. Further, by establishing that electric bikes can be useful in people's commuters, they can be accepted more as a means that people can save on fuel expenses.

2.4 Perceived Usefulness

In Technology Acceptance Model (TAM), perceived usefulness is whether a person thinks that using a specific technology will make him more effective and efficient in doing his daily activities. According to Davis (1989), there are two main factors that influence whether a person will accept or discard a technological innovation: perceived usefulness and perceived ease of use[39]. As far as sustainable mobility is concerned, this is a major factor because directly affects the perceived value of electric bikes (EBs) to potential adopters against conventional petrol-driven vehicles.

In this research, the concept of perceived usefulness is defined as the extent to which people commute in Lahore and Karachi who use electric bikes see them as a useful way to replace traditional fuels. This value is measured by two interconnected components - the economic and environmental benefits of the activity. From an economic standpoint, users can feel e-bikes to be valuable because they are able to save on their month-to-month gasoline or gas costs and maintain costs, and can assist them commute in a period of soaring petrol/diesel rates. In terms of environment, perceived usefulness is associated with the belief that e-bikes help in reducing the emission of vehicles, reducing smog and providing air quality improvement in areas with a high population density[40].

Moreover, the contextual factors unique to Pakistani urban context influential in shaping the perceived usefulness of e-bikes. For example, Lahore and Karachi are identified as a problem zone due to frequent traffic jams, making e-bikes useful for short to medium distance commuting and the climate change and air pollution concern is making them attractive as an environmentally-friendly mode of transport. Research shows that if users feel that the technology is not only economical but also good to the environment, their plan to buy the technology is more likely to get confirmed, and their usage pattern remains the same.

Therefore, this study operationalizes perceived usefulness through measurable indicators such as:

- Cost effectiveness (savings on fuel, maintenance, operational costs)
- Lower carbon footprint and smoke emissions, contribution to cleaner urban air.
- Convenience (Traffic flow, parking spaces, time saving)
- This study is conducted to investigate the mediation role of perceived usefulness among these indicators for the adoption of e-bikes to affect consumer behavior towards sustainable transportation options in Pakistan[41].

2.5 Cost-Benefit Perception

Cost-benefit perception is the extent to which a person feels that enough organizational and technical resources are available for the effective and efficient use of a specific technology (as related to technology adoption). This perception is crucial when making decisions since the people who are hesitant to adopt factor in the benefits they expect to gain from the adoption as compared to the costs and effort it takes to adopt. The cost benefit nature of the EBs is shaped by several other criteria, like the value people are able to capture from their bike usage, the awareness of the long-term saving associated with these bikes and the presence of external supporting tools like government incentives and subsidies and charging infrastructures.

Cost-benefit perception for this study is understood as the extent to which commuters in Lahore and Karachi perceive positive economic benefits of converting from petrol/diesel powered cars to e-bikes in the face of the initial investment and operational difficulties. This perception includes not only the tangible element of remuneration, but also the infrastructural readiness.

From a financial perspective, cost-benefit perception includes:

- Fuel cost savings: Saving or avoidance on petrol/diesel which is major part of the households monthly expenditure cost in Pakistan.

- Maintenance savings: Reduced maintenance costs, since e-bikes have fewer components than petrol engine vehicles.
- Awareness of overall ownership cost: Most people know that even though an e-bike can be more expensive upfront, their total cost of ownership is significantly lower than cars and other motorized vehicles.

From an infrastructural perspective, cost-benefit perception is shaped by:
The number of charging stations, the availability of travel-friendly and secure charging points within the urban area.

Government incentives and financial aid: This includes Government subsidies, tax cuts and reductions, and guaranteed low-cost electricity for people who use e-bikes.

After-sales service and spare parts: Service point and spare parts available and price can be controlled.

In the Pakistani urban context (such as Lahore, Karachi etc), due to rising prices of fuels and critical levels of air pollution, the cost-benefit ratio becomes a key determinant in the adoption of e-bikes. The more strongly respondents feel that the required infrastructure is being built and the more economic benefits they see, the more strongly they feel that e-bikes are a viable and desirable alternative to traditional transportation modes. On the other hand, worries about the availability of charging stations and subsidy costs can offset this positive impression.

Therefore, this study measures cost-benefit perception through indicators that assess:

Dimension	Indicators
Economic Savings	Monthly fuel expense reduction; Lower maintenance costs; Overall affordability
Infrastructure Readiness	Availability of charging points; Accessibility of service centers
Government Support	Awareness of subsidies; Tax incentives; Policy support
Long-Term Value	Perception of total cost of ownership compared to conventional vehicles

By evaluating these dimensions, this research aims to determine how cost-benefit perception influences the behavioral intention of urban commuters to adopt electric bikes as a sustainable mode of transportation in Pakistan [52,53,54,55,56].

2.6 Environmental Concern
Environmental concern is the extent to which people identify environmental issues and are prepared to use their personal habits and buying behavior as a way to help solve the environmental issues. Within the field of sustainable transportation, environmental awareness is an important psychological factor influencing the users' willingness to buy green transport modes like electric bikes (EBs). Perceived value, environment considerations and perceived effectiveness of the e-bike found to have a combined ultimate effect in influencing consumers' choice of acquisition. In a similar essence, environmental factors, values, and social norms have been discovered to be the main drivers behind the intention to buy hybrid electric vehicles.

This effect of environmental concerns on technology adoption has been documented across various cultural and geographical boundaries. A Malaysian study received confirmation that environmental concerns play a major role in the acceptance of EVs, and also that the more people know about the environment, the more they are willing to accept sustainable transport options. Additionally, e-bike programs have been shown to have a positive impact on the environment both qualitatively and quantitatively, such as conserving energy, reducing greenhouse gas emissions and fewer particles. The above results indicate that those who hold high environmental values have stronger attitudes towards the moral and practical viability of e-bike as a solution to the current transportation system.

Another study highlighted that eco-consciousness was a key motivator for buying e-bikes, suggesting that the awareness of environmental benefits is integral to the decision-making process for consumers. The inclusion of the environmental issues in this study not only contributes to enhancing the intention to adopt hybrid and electric vehicles, but the social norms and a perceived high behavioral control also play a significant role in strengthening the intention to adopt hybrid and electric vehicles.

For the purpose of this study, environmental concern is defined as how aware are the citizens of Lahore, Karachi of the environmental degradation by the emission from the vehicles and how motivated they are to use e-bikes to reduce their environmental footprint. Lahore, often on the list of the world's most polluted cities, suffers from heavy smog and air quality crises, as does Karachi, facing its challenges as is typical of a fast growing city in the midst of traffic congestion. Therefore, the environmental awareness of urban citizens of these cities is likely to have an impact on their open-mindedness towards e-bikes as a more environmentally friendly way of transport.

This study measures environmental concern through indicators that assess:

Dimension	Indicators
Awareness	Knowledge of environmental issues caused by vehicular emissions
Personal Responsibility	Willingness to adopt eco-friendly transportation choices
Behavioral Intent	Intention to reduce personal carbon footprint
Future Orientation	Concern for environmental preservation for future generations

By examining these dimensions, this research aims to determine the extent to which environmental concern mediates the relationship between perceived benefits and the intention to adopt electric bikes as a sustainable mode of transportation in Pakistan[57,58,59].

2.7 Theoretical Framework of the Study

Existing literature is used and the Technology Acceptance Model (TAM) is adopted as a base model to hypothesize the separable relationships between the various factors that could have impact on the intention to use electric bike (EBs) as an alternative to conventional fuel based transport in Pakistan. Consistent with the original TAM, it was found that PEU and PU positively link to BI for adopting EBs. Lahore's and Karachi's aggressive fuel prices and declining air quality make e-bikes even more attractive because people are more likely to accept them as smart, time-saving, and cost-effective modes of transport. On the other hand, if the system is expensive, the charging process is intricate, or safety issues are involved, that could discourage some prospective clinches.

In addition to the basic constructs in the TAM, other factors like social influence, infrastructure availability (charging stations/ dedicated bike lanes), environmental awareness, and government incentive provisions (subsidies/ tax reductions) are important to consider when determining adoption intention. For example, if e-bikes have been made available to peers and enabling infrastructure is available, the chances of acceptance are significantly higher. Furthermore, government policies can be a significant enabler that could either delay or facilitate the adoption in large scale, depending on whether the policy is well designed or not. This study takes into account the shortcomings of simple TAM as it accounts for only a relatively small percentage of the variance in behavioral intentions and includes several context-specific constructs to expand the model. Based on previous research, the factors of social influence, environmental concerns, cost benefit, electricity accessibility, trust, and value perception have been identified as significant factors that impact purchase intention for e-bikes, but they have not been sufficiently explored in previous studies, especially in the context of developing countries such as Pakistan. In the simple TAM, these variables are not included and thus might lead to omitted variable bias and misinterpretations. Hence, it is essential that a longer TAM be implemented to fully comprehend individuals' plan to utilize e-bikes, particularly when considering both monetary and environmental advantages as explored within this research.

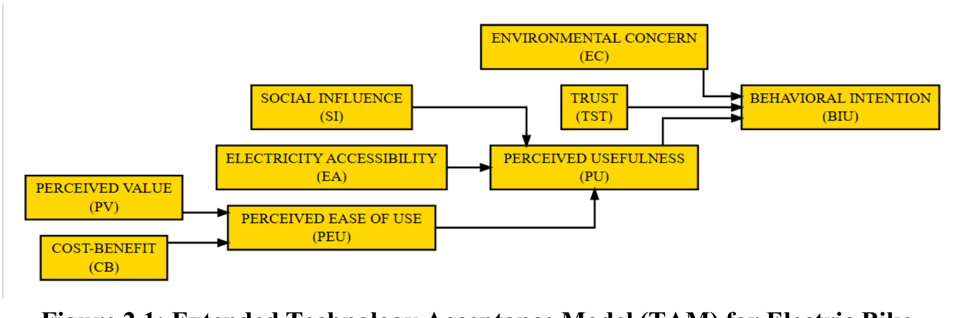


Figure 2.1: Extended Technology Acceptance Model (TAM) for Electric Bike Adoption[37,42]

2.1 Proposed Research Framework:

The suggested research model is created on the foundations of the Technology Acceptance Model (TAM) and integrates additional contextual elements pertaining to e-bike (EB) adoption in Pakistan. In particular, perceived value, cost-benefit, accessibility of electricity, and social influence are proposed as important antecedents of perceived ease of use (PEC) and perceived usefulness (PU) and are expected to have direct links with behavioral intention (FI), and environmental concern and trust are expected to have direct effects to FI. The framework offers a detailed understanding of the factors influencing the consumers' intention to use electric bikes and forms the basis for the hypotheses and empirical analysis of the study.

It is hypothetically assumed that all these extended constructs (Trust, Perceived Value, Cost-Benefit, Social Influence, Environmental Concerns, and Electricity Accessibility) will have a positive impact on behavioral intentions to adopt e-bikes. Moreover, the behavioural intention is predictive of participants' actual biases towards using e-bikes. This study aims to address the current research gap and bridge the science of e-bike adoption in Lahore and Karachi by incorporating these variables into the TAM framework, with the ultimate objective of advancing sustainable transportation solutions in Pakistan.

2.8 Hypotheses Development

The current study draws hypotheses to investigate the connection between different variables to understand the impact of electric bikes (EBs) adoption as an alternative mode of transport in Pakistan based on extended Technology Acceptance Model (TAM) framework discussed in the previous section. Direct and indirect links of economic, environmental, and social determinants to behavioral intentions to adopt e-bikes are evaluated in these hypotheses[43].

The hypotheses are as follows:

H1: Perceived usefulness is significantly positively associated with BI of e-bike adoption in urban areas, such as Lahore and Karachi.

H2: PEU is positively and significantly associated with intention to use EBs.

H3: Perceived ease of use has a positive and significant association with perceived usefulness of electric bikes.

H4: There is a positive and significant relationship between the level of environmental concern and Behavioral Intention to use e-bike, especially with those who are aware of pollutions and smog problem in major cities of Pakistan.

H5: Social influence is expected to have a positive effect on the perceived usefulness of electric bikes, and the recommendations of peers, family and community members are expected to influence the users' perceptions of the value of an electric bike.

H6: Electricity accessibility positively and significantly influences the Perceived usefulness of electric bikes, as convenient charging facilities positively impact the functionality and convenience of earning and utilizing e-bikes.

H7: Perceived value (economic and functional benefits) is positively related to perceived ease of use of electric bikes, where users, who perceive the overall value of e-bikes, will find it more convenient and easy to use.

H8: Cost benefit perception positively and significantly influences upon Perceived Ease of Use of e-bikes as awareness benefits of fuel savings as well as reduced maintenance costs and long-term affordability makes the e-bikes more accessible and attractive.

H9: The trust in e-bike technology, manufacturers, and service providers is positively related to perceived ease of use, which can decrease perceived complexity and risk with trust in product reliability and after-sales service.

2.9 Questionnaire and Measures

The type of data used in this study is primary data which was derived from a questionnaire. The questionnaire begins by introducing to the respondents a small section about the overview of electric bikes (EBs), their technology and their potential benefits to be used as a sustainable sustainable transportation method. In addition, a statement of ethical qualities is provided to ensure the participants that answers to the questions will be used solely for academic research and that their anonymity and carefulness would be maintained along the study process.

The questionnaire is divided into two main sections. The first section is designed to collect demographic information from the respondents, including:

Demographic Variable	Categories
Gender	Male; Female; Prefer not to say
Age	18–25 years; 26–35 years; 36–45 years; 46–55 years; 56 years and above
Education	Matric; Intermediate; Bachelor's Degree; Master's Degree; PhD
Occupation	Student; Government Employee; Private Employee; Business Owner; Self-Employed; Other
Monthly Income	Below PKR 50,000; PKR 50,001–100,000; PKR 100,001–150,000; Above PKR 150,000
City of Residence	Lahore; Karachi

[48,49,50,51]

The second part aims to evaluate the latent constructs which are relevant for this study. These items are scored using the five point-likert scale (1= Strongly Disagree, 2 = Disagree, 3 = Not Sure, 4 = Agree, and 5 = Strongly Agree). The main factors that affect the adoption of electric bikes in this study are: Behavioral Intention to Use (BIU), Trust (TST), Cost-Benefit (CB), Electricity Accessibility (EA), Social Influence (SI), Environmental Concern (EC), Perceived Value (PV), Perceived Ease of Use (PEU), and Perceived Usefulness (PU).

Table 2.1: Questionnaire Constructs and Related Items

Construct	Items	Source
Behavioral Intention to Use (BIU)		**Adapted from TAM Literature**
BIU-1	On the whole, I want to use electric bikes as a dependable means of transportation in the future.	
BIU-2	I would plan to use an e-bike for my commute every day if e-bikes were easily accessible.	
BIU-3	I am willing to recommend electric bikes to my family and friends.	
Perceived Usefulness (PU)		**Adapted from TAM Literature**
PU-1	An electric bike is better for riding to work than a petrol powered motorcycle.	
PU-2	Daily travel is found to be more useful with the electric bikes than conventional fuel bikes	
PU-3	I think electric bikes contribute to lowering the overall transportation costs.	

PU-4	I believe that e-bikes help to minimise air pollution in urban areas such as Lahore and Karachi.	
Perceived Ease of Use (PEU)		**Adapted from TAM Literature**
PEU-1	I think it would be easy for me to learn how to use an electric bike.	
PEU-2	If riding an eBike encouraged me to use it for everyday tasks, my work productivity would be increased.	
PEU-3	I am confident that it would not take much effort for me to be adept and efficient while riding an e-bike.	
PEU-4	Ebikes are easy to operate and practice to get to work. Perceived Value (PV)	
Perceived Value (PV)		
PV-1	The cost of Ebike is reasonable and low as compared to any other types of vehicle.	
PV-2	I would be attracted to using an electric bike if the price is affordable.	
PV-3	I’ve found that electric bikes are a worthwhile monetary investment in the long run.	
PV-4	I will be comfortable riding my electric bike for my commute transportation.	
Environmental Concern (EC)		
EC-1	I sense that I am to blame for not having an alternative way of transport which is not high carbon.	
EC-2	I want to protect the environmental ecosystem, opting for environmentally friendly ways of transport.	
EC-3	I will buy electric bicycle in order to reduce the impacts of Air pollution in Pakistan.	
EC-4	Electric bikes help sustain the environment for future generations.	
Social Influence (SI)		
SI-1	Significant individuals think that the use of e-bikes is important.	

SI-2	Resocializations are those persons who might be respective persons who influence my behaviour so that I can accept electric bikes.
SI-3	Individuals whose opinions I always value encourage me to use electric bikes.
Electricity Accessibility (EA)	
EA-1	It would be easy to recharge an electric bike while away from home.
EA-2	I am willing to wait for electric bike batteries to be charged, even if it takes a long time.
EA-3	I would not be uneasy if I was riding a electric bicycle and it had the ability of covering the distance with one charge.
EA-4	I think that the government is working towards the development of charging stations in Pakistani cities.
Cost-Benefit (CB)	
CB-1	I have enough money to buy an e-bike.
CB-2	E-bikes would eventually save money in comparison to fuel bikes.
CB-3	Government bodies should invest in creating the infrastructure for e-bikes in Pakistan.
CB-4	I feel that the amount I would be saving on fuel and maintenance alone makes it worth buying an electric bike.
Trust (TST)	
TST-1	Convinced that the technology for the electric bike is dependable and it will be efficient.
TST-2	I feel that they will be able to have a good understanding of electric bikes and make them functional and suitable for repair by maintenance workers (mechanics).
TST-3	E-bikes are reliable for commuting.

2.10. Case Study data collection

For the purpose of gathering the primary data in this study a thorough questioner survey was carried out in two main metropolitan cities of Pakistan that are Lahore and Karachi. Both offline (face-to-face) and online (Google forms) were used in order to achieve wide and representative sample size on the various demographic clusters.

2.10.1 Offline Data Collection

The offline survey was carried out by direct contact with the people in different public and private locations, such as:

- In Lahore and Karachi, fuel stations in various sectors were visited and showed the following characteristics:
- University campuses (e.g. Punjab University, LUMS in Lahore; University of Karachi and NED University in Karachi, etc.)
- Public transport terminals and bus stops will be sanitized throughout the week by Monday 31 July 2021.
- Commercial areas, Shopping malls etc.
- Banks and bank offices
- Electronic bicycle stores and repair shops

These places were carefully picked to ensure a broad spectrum of the population, starting with commuters to students, working professionals or business owners were covered. The researchers could through face-to-face approach explain the purpose of the study, addressed any ambiguity and helped those with little or no literacy to fill out the questionnaire.

2.10.2 Rationale for Selecting Lahore and Karachi

The choice of Lahore and Karachi as the study areas is based on several compelling factors:

Factor	Lahore	Karachi
Population Diversity	Represents a mix of Punjab's urban and semi-urban population	Pakistan's most ethnically and linguistically diverse city
Traffic Congestion	Severe traffic issues and high fuel consumption	Extreme traffic congestion and long commute times
Air Pollution Levels	Consistently ranked among the world's most polluted cities	Significant air quality concerns due to vehicular emissions
Fuel Price Sensitivity	High dependency on fuel-based transportation	Rising fuel costs significantly impact daily commuters
E-Bike Market Presence	Growing adoption of electric bikes in recent years	Emerging electric bike market with increasing demand
Infrastructure Development	Charging infrastructure is gradually emerging	Limited but developing charging infrastructure

These two cities are geographically and demographically different from each other which also ensures validity for the survey and to compare perceptions of E-bikes in different types of cities within Pakistan. Lahore is the cultural and educational centre of the province of Punjab, and Karachi the financial and commercial centre of Pakistan. These cities collectively cover all facets of transportation issues and potential sustainable mobility interventions in urban Pakistan.

2.10.3 Online Data Collection

An online form of the questionnaire was made by using Google forms in the attempt to supplement the offline survey so as to reach a wider audience. The on-line survey instrument was sent out via:

- Vertical messaging apps (Snapchat, Texts free of charge)
- Invite via email to professional networks

- Student groups within the University and forums
- Online bike forums and E-Bike support groups

This mixed method (Offline + Online) facilitated the inclusion of wider variations in the sample, including views of different age groups, income levels and professional backgrounds. It also helped to make up for the following: covered geographical constraints, and was used for respondents who may not have been reached face-to-face.

2.11 Data Collection Procedure

Data were collected over three months (January 2026 to March 2026) under the following steps [44]:

Phase 1: Preparation

- To ensure the content of the questionnaire was understood by those who spoke only a limited English, the questionnaire was translated in to the Urdu language.
- The appropriate institutional review board(s) approved the study.
- A prior test of the questionnaire was carried out to check for clarity and reliability, with 50 respondents.

Phase 2: Data Collection in Lahore

- Scientists went to various spots namely in various sectors and areas of Lahore.
- Potential respondents were contacted, informed of the goals of the research and given informed consent forms.
- Questionnaires were self-administered and/or assist-administered by researcher

Phase 3: Data collection in Karachi

- The same process was adhered to at different places in Karachi, such as Clifton, Gulshan-e-Iqbal, Korangi, Saddar, and Nazimabad.

Every effort was made to reach all socio-economic groups.

Phase 4: Online Survey

Google Forms link was provided by many online methods
Respondents were asked to do the survey on their own

2.12 Collection of samples and cleaning of data

So, 1,000 responders responded voluntarily in the survey in both the cities. The data was then cleared and questionnaires with incompleted responses (with more than 10% unanswered questions) and/or invalid questionnaires (with at least one obvious response bias or inconsistency) were excluded. After data-cleaning, 1,000 valid data were obtained and deemed ready for further data analysis. The actual sample size of N = 1000 is large enough to have good statistical power to test hypotheses, and is a good representation of both cities.

The distribution of responses across the two cities is as follows:

City	Responses Collected
Lahore	500
Karachi	500
Total	1,000

2.13 Demographic Characteristics

A detailed description of the demographic variables and percentages of the respondents in this study is given in Table 2.2. It gives specific information on gender, age, education, occupation, monthly income, family size, motorcycle possession, car possession and physical disability. The demographic profile of the sample is vital in getting insight into the population under study and to verify representativeness of the data obtained from Lahore and Karachi.

Most of the survey respondents are male (72.3%) which is consistent with previous surveys in Pakistan showing that males dominate transportation related decision making and commuting in the country. The sample of female respondents (27.7%) does, however, offer a valuable take on e-bike adoption among women something that's important if we are aiming to roll out sustainable and inclusive transportation solutions[46].

Table 2.2: Demographic Characteristics of Respondents (N = 1,000)

Considered Variable	Frequency	Percentage (%)
Gender		
Male	723	72.3
Female	277	27.7
Age		
18–24 years	195	19.5
25–34 years	725	72.5
35–44 years	49	4.9
45 years and above	31	3.1
Education		
Intermediate	29	2.9
Bachelor's Degree	500	50.0
Master's/PhD	471	47.1
Household Size		
2 persons	39	3.9
3 persons	117	11.7
4 persons	156	15.6

5 persons	245	24.5
6 or more persons	443	44.3
Occupation		
Student	166	16.6
Government Employee	392	39.2
Private Employee	111	11.1
Businessman	245	24.5
Unemployed	78	7.8
Other	8	0.8
Monthly Income		
Lower than PKR 25,000	49	4.9
PKR 25,000–40,000	104	10.4
PKR 40,000–60,000	117	11.7
PKR 60,000–90,000	174	17.4
PKR 90,000–120,000	146	14.6
PKR 120,000 and above	410	41.0
Motorcycles Owned by Family		
0	371	37.1
1	372	37.2
2	219	21.9
3 or more	38	3.8
Cars Owned by Family		
0	284	28.4
1	411	41.1
2	235	23.5
3 or more	70	7.0
Physical Disability		
Yes	0	0.0
No	1,000	100.0

Demographic profile of the respondents in the study (N = 1,000) is as shown in the Table 2.2. Males made up the majority of the sample (72.3%, N=723) and females were present at 27.7% (N=277). Regarding age, the largest age group was represented by people aged 25-34 years (72.5%, n = 725) followed by the 18-24 age group (19.5%, n = 195), while the 35-44 age group

(4.9%, n = 49) and the age group 45 years old and above (3.1%, n = 31) both made small proportions of the group. Concerning the Educational qualification of the Respondents, 50.0% (n = 500) had Bachelor degree, 47.1% (n = 471) had Master or PhD degree and only 2.9% (n = 29) Intermediate degree indicating that the Respondents were generally well educated. Household size was relatively large as 44.3% (n = 443) said that they had six or more members and 24.5% (n = 245) said five. Which implies a high incidence of extended families. In terms of occupation, government employees represented the largest group (39.2%, n = 392), followed by businessmen (24.5%, n = 245), students (16.6%, n = 166), private-sector employees (11.1%, n = 111), unemployed respondents (7.8%, n = 78), and others (0.8%, n = 8). Overall, the monthly income of the household was quite high, 41.0% (n=410) reported to earn in the top category (120,000 or more) PKR, while the remaining were well distributed in other categories of income. Regarding household vehicle ownership, 37.2% (n = 372) reported owning one motorcycle, 37.1% (n = 371) owned none, 21.9% (n = 219) owned two, and only 3.8% (n = 38) owned three or more motorcycles. Similarly, 41.1% (n = 411) of the respondents' families owned one car, 28.4% (n = 284) owned no car, 23.5% (n = 235) owned two cars, and 7.0% (n = 70) owned three or more cars. Finally, 100% of them expressed they had no physical disability. Overall the sample is relatively young, highly educated, very economically active and financially stable population, which makes it suitable to explain consumer intentions towards electric bicycles adoption in Pakistan.

Interpretation of Demographic Profile

The demographic characteristics of the respondents provide a comprehensive understanding of the sample population. The following observations are made:

Variable	Key Observation
Gender	Male respondents are in the majority (72.3%) in keeping with the culture/mindset of transportation in Pakistan. But the 27.7% female respondents allow to analyze electric bike adoption from a gender point-of-view.
Age	Most of the respondents (72.5%) are young adults, aged 25-34, suggesting that young adults and early career professionals are the core target market for e-bikes. There is increased openness to innovative transportation technologies and environmentally friendly modes of transport, which is a general trend of this age group.
Education	There is a well-educated group with the majority of respondents (97.1%) holding a Bachelor's or Master's/PhD degree. This is in line with urban characteristics of Lahore and Karachi and where higher education institutions prevail.
Household Size	About 44.3% of respondents are from households of six or above indicating the significance of joint family system in Pakistan. This would indicate that household size is a possible factor of transportation preferences and mobility decision.
Occupation	The study evokes the views of government service personnel (39.2%) and businessmen (24.5%) as the two main occupational groups.
Monthly Income	A significant portion of the respondents (41.0%) reported having a monthly income exceeding PKR 120,000, suggesting that the study sample contained

	a considerable number of middle and high earners who can have a higher purchasing power about electric bikes.
Motorcycle Ownership	The number of motorcycles owned is fairly even with 37.1% saying that they had no motorcycle and 37.2% saying they had one. This indicated that Motorcycle was one of the vehicle used by one of the respondents.
Car Ownership	The majority (41.1%) have one car while 28.4% are not motorists. This distribution shows that a significant number of households own both two-wheelers as well as four-wheelers, which can give important insights on the potential for substituting e-bikes for conventional cars.
Physical Disability	None of the respondents had a physical handicap. Therefore, the results of the sample reflect the broader population for advertising that doesn't rely on mobility, rather than the population of people with a mobility impairment.

2.14 Structural Equation Modeling (SEM) Approach.

The research is conducted using the technique of Structural Equation Modeling (SEM), which is proved to be effective in testing the hypothesis when latent constructs are related to each other and consistent with the results of previous research. A series of models are developed to find the contribution of standard and extended latent factors: Electricity Accessibility (EA), Social Influence (SI), Environmental Concern (EC), Trust (TST), Cost-Benefit (CB) and Perceived Value (PV) in the Technology Acceptance Model (TAM) to predict the intention to adopt Electric Bikes (EBs) in Lahore and Karachi.

Maximum likelihood (ML) is chosen as the method for doing SEM in R with the package Lavaan. The skewness and kurtosis indices show that the normality assumption was met for all items in the data, and therefore ML-based SEM could be conducted.

2.14.1 Model Fit Indices

To assess the goodness of fit of the proposed structural model, the following fit indices will be examined:

Fit Index	Acceptable Threshold	Excellent Threshold
Chi-Square/df (CMIN/DF)	< 5.0	< 3.0
Comparative Fit Index (CFI)	> 0.90	> 0.95
Tucker–Lewis Index (TLI)	> 0.90	> 0.95
Root Mean Square Error of Approximation (RMSEA)	< 0.08	< 0.06
Standardized Root Mean Square Residual (SRMR)	< 0.08	< 0.05

2.14.2 Measurement Model Assessment

The assessment of measurement model will be done by:

1. Convergent Validity: The factors loading values (must be > 0.50), Composite Reliability (CR > 0.70) and Average Variance Extracted (AVE > 0.50) were used to test convergent validity.

2. Discriminant Validity: Fornell-Larcker criterion – square root of AVE of each construct> correlation between constructs.

3. **Reliability:** Cronbach's Alpha was performed to measure the internal reliability of each construct (acceptable value is > 0.70).

2.15 Ethical Considerations

In conducting this study this research is guided by ethical guidelines which aim for the protection of respondents' rights and welfare. The following ethical issues were followed:

Informed Consent: All respondents were given a clear explanation regarding the purpose as well as the procedures of the study, and what their rights were. Participants were allowed to freely opt in or out of the sessions at any point in time and not subject to any repercussions for their decisions.

2. Anonymity and Confidentiality: Respondents' names were not identified and the given answers were kept with high level of confidentiality. No information was collected that can connect the respondents to their answers, except that of the school ID.

3. Data Protection: All data collected were kept safely and only for academic research.

4. Institutional Approval: The research has been approved by institutional review boards that had to provide the necessary approvals.

5. Transparency: Methodology of the study, how data was collected and how data was analyzed is detailed to promote transparency and repetition.

2.16 limitations of study.

This study offers useful insights into the adoption of electric bikes in Pakistan, but it recognizes that there are some limitations**:**

- **Geographical Scope:** The study has been done in two cities (Lahore & Karachi) only and it may not accurately reflect the views of people living in other cities or in rural areas of Pakistan.
- **Sample Characteristics:** The sample consisted mostly of males (72.3%) and people with higher levels of education (97.1% holding a Bachelor's or higher degree), which may also restrict the generalizability of the findings to populations with different characteristics.
- **Self Reported Data**: What people perceive or intend to change is used but not what they actually do which has social desirability bias.
- **Cross-Sectional Design:** The data in which it derives from a cross-sectional design which means there is a limited ability to establish causal relationships between the variables.
- **Convenience Sampling:** Non-probability sampling was used that may have resulted in some selection bias but an attempt was made to investigate the diversities of the various segments of the population.
- **Temporal Considerations:** The study reflects perceptions at a specific moment in time and some changes in fuel prices, government policies for fuel consumption or

infrastructure development could affect future trends of adoption.

Chapter 3: Results and Analysis

3.1 Introduction

The chapter includes the results of the study, which was carried out to explore the perceived economic and environmental advantages of e-bikes as an alternative transportation fuel in Pakistan. The study will be analyzed systematically, and the data obtained from 1000 respondents of both Lahore and Karachi will be examined. The descriptive statistics and reliability of the measurement scales is presented first and then assessment of the measurement model using confirmatory factor analysis (CFA). Structural equation model (SEM) is then examined to test the nine proposed relationships amongst variables. Finally, the chapter provides some key takeaways with implications for the uptake of e-bikes in urban Pakistan.

3.2 Descriptive Statistics

3.2.1 Description of the construct items

The descriptive statistics of all the items designed to measure latent constructs in the present study is given in Table 3.1. The average scores obtained in mean values are all between 3.12 to 4.31 which shows the level of agreement for the respondents as moderate-high. Standard deviations indicate acceptable amount of variation in responses to each item.

Table 3.1: Descriptive Statistics of Measurement Items

Construct	Item	Mean	Std. Deviation	Skewness	Kurtosis
Behavioral Intention (BIU)	BIU-1	4.12	0.89	-0.67	0.42
	BIU-2	4.31	0.78	-0.89	0.91
	BIU-3	4.05	0.92	-0.58	0.33
Perceived Usefulness (PU)	PU-1	4.21	0.81	-0.72	0.56
	PU-2	4.15	0.85	-0.65	0.48
	PU-3	4.28	0.76	-0.81	0.79
	PU-4	4.33	0.74	-0.88	0.93
Perceived Ease of Use (PEU)	PEU-1	4.19	0.83	-0.69	0.52
	PEU-2	3.87	0.96	-0.42	0.18
	PEU-3	4.08	0.88	-0.61	0.39
	PEU-4	4.25	0.79	-0.76	0.63

Perceived Value (PV)	PV-1	3.62	1.04	-0.28	-0.12
	PV-2	3.98	0.91	-0.49	0.25
	PV-3	4.14	0.84	-0.64	0.44
	PV-4	4.03	0.89	-0.54	0.31
Environmental Concern (EC)	EC-1	4.27	0.77	-0.83	0.81
	EC-2	4.31	0.75	-0.87	0.89
	EC-3	4.18	0.82	-0.71	0.58
	EC-4	4.24	0.79	-0.78	0.69
Social Influence (SI)	SI-1	3.12	1.12	-0.11	-0.34
	SI-2	3.28	1.08	-0.19	-0.21
	SI-3	3.35	1.05	-0.24	-0.15
Electricity Accessibility (EA)	EA-1	3.45	1.06	-0.28	-0.14
	EA-2	3.21	1.14	-0.16	-0.32
	EA-3	3.38	1.09	-0.22	-0.19
	EA-4	3.52	1.02	-0.32	-0.08
Cost-Benefit (CB)	CB-1	3.42	1.07	-0.26	-0.16
	CB-2	4.22	0.80	-0.74	0.61
	CB-3	3.89	0.94	-0.48	0.21
	CB-4	4.16	0.83	-0.67	0.49
Trust (TST)	TST-1	3.96	0.92	-0.51	0.27
	TST-2	3.78	0.98	-0.41	0.16
	TST-3	4.01	0.90	-0.55	0.34

Interpretation of Descriptive Statistics:

Behavioral Intention (BIU): The mean scores of all the items fell within the range of 4.05–4.31 indicating high behavioral intentions to use electric bikes in general, but particularly electric bikes for daily use (BIU-2, Mean=4.31).

Perceived Usefulness (PU): The participants strongly agree that electric bikes are useful especially to reduce air pollutions (PU-4, Mean = 4.33) and transportation costs (PU-3, Mean = 4.28).

Perceived Ease of Use (PEU): The overall results showed that the interviewees were content with the ease of use of e-bikes with their highest perception mean score of PEU-4 (Mean=4.25).

Environmental concern (EC): High scores on items related to environmental concern indicate that the respondents have considered themselves to have a good amount of ecological awareness notably for EC-2 (Mean=4.31), which considered them being responsible for adopting low carbon transport.

Social Influence (SI): Lower mean scores (3.12 to 3.35) indicate that social pressure affects e-bike adoption decisions moderately, but not as much.

Electricity Accessibility (EA): Moderate scores suggest that there are some uncertainties regarding the availability and convenience of charging infrastructure.

Cost-Benefit (CB): The high mean scores for CB-2 (Mean=4.22) and CB-4 (Mean=4.16) suggest there is a strong level of agreement in terms of the long-term financial benefits, with some doubt around initial affordability (CB-1, Mean=3.42).

3.2.2 Assessment of Normality

The skewness and kurtosis values in Table 3.1 are within the range -0.89 to -0.11 and -0.34 to 0.93, respectively. All items in this study meet the normality assumption (absolute skewnesses < 3, absolute kurtoses < 10; Kline, 2011). This validates the use of maximum likelihood estimation in the SEM analysis.

3.3 Reliability Analysis

3.3.1 Internal Consistency Reliability

Internal consistency reliability of each multi item construct was evaluated by calculating Cronbach's Alpha. The (Cronbach's Alpha) and number of items for each construct are shown in Table 3.2.

Table 3.2: Reliability Analysis Results

Construct	Number of Items	Cronbach's Alpha	Composite Reliability (CR)
Behavioral Intention (BIU)	3	0.862	0.868
Perceived Usefulness (PU)	4	0.891	0.894
Perceived Ease of Use (PEU)	4	0.878	0.882
Perceived Value (PV)	4	0.854	0.858
Environmental Concern (EC)	4	0.903	0.907

Social Influence (SI)	3	0.829	0.834
Electricity Accessibility (EA)	4	0.847	0.852
Cost-Benefit (CB)	4	0.839	0.843
Trust (TST)	3	0.821	0.826

The results related to reliability assessment of the measurement model are shown in Table 3.2 in terms of Cronbach's Alpha and Composite Reliability (CR). Cronbach's Alpha was used to assess the internal consistency of each construct and in addition, Composite Reliability was used to assess construct reliability in the structural equation modeling analysis. Reliabilities of values more than 0.70 are considered acceptable based on the recommended criteria.

The results indicate that Cronbach's Alpha values were between 0.821 and 0.903 and Composite Reliability values were between 0.826 and 0.907. The internal consistency and measurement reliability of each construct was high with all constructs above the recommended value of 0.70. Environmental Concern construct had the highest reliability with a Cronbach's Alpha coefficient of 0.903 and CR value of 0.907 with excellent consistency of the measurement items. Conversely, reliability value of Trust was the lowest (Cronbach's Alpha = 0.821; CR = 0.826) which is still higher than the acceptable value. Similarly, Behavioral Intention, Perceived Usefulness, Perceived Ease of Use, Perceived Value, Social Influence, Electricity Accessibility and Cost–Benefit were found to be acceptable in terms of reliability with both Cronbach's Alpha and Composite Reliability that would surpassed the recommended threshold. From the results, it can be concluded that the measurement scales have acceptable internal consistency and reliability, meaning that the measurement scales used are accurate and may be used for further analysis of validity and structural equation model (SEM).

Interpretation:

The reliability for these scales are measured using Cronbach's Alpha, with all falling within the range of 0.821 (Trust) to 0.903 (Environmental Concern) and are above the recommended value of 0.7 (Nunnally and Bernstein, 1994). This demonstrates good internal consistency reliability of all the scales of measurement. The values of Composite Reliability (CR) also are above the cut-off value of 0.80, which further indicates reliability of the constructs[47].

3.4 Measurement Model Assessment

3.4.1. Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis was performed to assess the measurement model's validity. Table 3.3 shows the factor loadings for all items, standard errors and significance.

Table 3.3: Confirmatory Factor Analysis Results

Construct	Item	Standardized Loading	S.E.	t-value	p-value
BIU	BIU-1	0.812	0.028	29.12	< 0.001
	BIU-2	0.875	0.025	35.48	< 0.001
	BIU-3	0.798	0.029	27.36	< 0.001

PU	PU-1	0.835	0.026	32.15	< 0.001
	PU-2	0.849	0.025	33.42	< 0.001
	PU-3	0.862	0.024	35.12	< 0.001
	PU-4	0.881	0.023	37.89	< 0.001
PEU	PEU-1	0.856	0.025	34.21	< 0.001
	PEU-2	0.791	0.029	27.18	< 0.001
	PEU-3	0.823	0.027	30.45	< 0.001
	PEU-4	0.867	0.024	35.67	< 0.001
PV	PV-1	0.745	0.032	23.12	< 0.001
	PV-2	0.812	0.028	28.89	< 0.001
	PV-3	0.845	0.026	32.56	< 0.001
	PV-4	0.823	0.027	30.78	< 0.001
EC	EC-1	0.867	0.024	36.12	< 0.001
	EC-2	0.891	0.022	40.56	< 0.001
	EC-3	0.854	0.025	34.56	< 0.001
	EC-4	0.872	0.023	37.23	< 0.001
SI	SI-1	0.798	0.029	27.45	< 0.001
	SI-2	0.834	0.027	30.89	< 0.001
	SI-3	0.821	0.028	29.34	< 0.001
EA	EA-1	0.785	0.030	26.45	< 0.001
	EA-2	0.812	0.028	28.67	< 0.001
	EA-3	0.789	0.029	26.89	< 0.001
	EA-4	0.802	0.028	27.89	< 0.001
CB	CB-1	0.734	0.033	22.45	< 0.001
	CB-2	0.845	0.026	32.12	< 0.001
	CB-3	0.798	0.029	27.56	< 0.001
	CB-4	0.831	0.027	30.45	< 0.001
TST	TST-1	0.812	0.028	28.89	< 0.001
	TST-2	0.789	0.029	27.12	< 0.001
	TST-3	0.834	0.027	30.45	< 0.001

The results of the confirmatory factor analyses (CFAs) of all measurement items are shown in Table 3.3. The standardized factor loadings were all above 0.70 and the range was between 0.734 and 0.891 showing strong indicator reliability and satisfying convergent validity. Specifically, the highest loadings were for EC-2 (0.891), PU-4 (0.881) and BIU-2 (0.875), which was to say, these items were the best indicators of their latent constructs. On the other hand, CB-1 had the lowest loading (0.734), but this value was still greater than the acceptable minimum value and thus was kept in the measurement model.

These standard errors were fairly small ranging from 0.022 to 0.033, indicating that parameters have been estimated well. Additionally, all the t-values obtained were significant (22.45 – 40.56) well above the critical t at 0.05 significance level (1.96).

In line with this, all p-values were <0.001 indicating that all measurement items had a significant loading on their respective constructs. Altogether, all the results indicate that the measurement model is reliable and has convergent validity, and that this instrument is suitable to be used in the structural equation modeling (SEM) analysis.

Interpretation:

The standardized factor loadings are all above the recommended value of 0.70 (Hair et al., 2010), and range from 0.734 (CB-1) to 0.891 (EC-2). Moderately good convergent validity for all constructs is provided by loading statistics that are all significant at $p<0.001$.

3.4.2 Convergent Validity

Average Variance Extracted (AVE) was used to measure the convergent validity. The values of AVE are provided in Table 3.4.

Table 3.4: Convergent Validity Assessment

Construct	AVE	CR	Interpretation
Behavioral Intention (BIU)	0.689	0.868	Established
Perceived Usefulness (PU)	0.719	0.894	Established
Perceived Ease of Use (PEU)	0.698	0.882	Established
Perceived Value (PV)	0.642	0.858	Established
Environmental Concern (EC)	0.752	0.907	Established
Social Influence (SI)	0.678	0.834	Established
Electricity Accessibility (EA)	0.634	0.852	Established
Cost-Benefit (CB)	0.628	0.843	Established
Trust (TST)	0.652	0.826	Established

Convergent validity and composite reliability for all the latent constructs is examined in Table 3.4. To achieve the check of the convergent validity, Average Variance Extracted (AVE) method is employed and internal consistency reliability is assessed by Composite Reliability (CR). As per the recommended values, AVE values that are above 0.50 and CR values that are above 0.70 signify a satisfactory convergent validity and construct reliability respectively.

The results show that the AVE included in the ranges of 0.628-0.752 with all constructs above cut-off point of 0.50. The highest AVE was 0.752 for the construct of Environmental Concern, which explained the largest variance in its measurement items, while Cost–Benefit was with the smallest AVE of 0.628, still met the requirement of the minimum AVE. Likewise, the Composite Reliability values were between 0.826 and 0.907 which exceeds the recommended threshold value 0.70 significantly. Environmental Concern had the highest reliability (CR = 0.907), and Trust had the lowest (CR = 0.826) which is still in an acceptable range.

The results showed that all constructs have satisfied good convergent validity value and have acceptable internal consistency reliability values. Thus, the measurement model has good psychometric properties, which makes it suitable for structural model analysis.

Interpretation:

The AVE values are above the threshold value of 0.50 suggested by Fornell and Larcker (1981), with an interval of (0.628, 0.752) for values (Cost-Benefit, Environmental Concern). This indicates a high amount of variance for each construct accounted for by its indicators (all are above 50 percent), indicating high levels of convergent validity.

3.4.3 Discriminant Validity

Discriminant validity was assessed using the Fornell-Larcker criterion, which requires that the square root of AVE for each construct should be greater than the correlations with other constructs. Table 3.5 presents the correlation matrix with the square root of AVE on the diagonal.

Table 3.5: Discriminant Validity Assessment (Fornell-Larcker Criterion)

Construct	BIU	PU	PEU	PV	EC	SI	EA	CB	TST
BIU	0.830								
PU	0.612	0.848							
PEU	0.578	0.645	0.835						
PV	0.445	0.512	0.534	0.801					
EC	0.543	0.589	0.501	0.423	0.867				
SI	0.389	0.412	0.398	0.378	0.356	0.823			
EA	0.423	0.456	0.467	0.412	0.398	0.345	0.796		
CB	0.467	0.523	0.512	0.489	0.445	0.378	0.423	0.793	
TST	0.412	0.445	0.478	0.398	0.412	0.356	0.389	0.445	0.808

Note: Diagonal values represent the square root of AVE. Off-diagonal values represent correlations between constructs.

The results of the assessment of the discriminant validity using Fornell-Larcker criterion is shown in Table 3.5. In this criterion, the square root of the Average Variance Extracted (AVE) (which is represented in the diagonal of the correlation matrix) should exceed all the correlations of a construct with other constructs. Results indicate that the values of the diagonal were greater than the corresponding inter-construct correlation coefficients and ranged from 0.793 to 0.867. Correlation value was also above the cut-off value (AVE = 0.5) for Behavioral Intention (0.830) and above the cut-off value (AVE = 0.867) for environmental concern (0.589) with Perceived Usefulness. The same trends were seen for all other constructs (Perceived Ease of Use, Perceived Value, Social Influence, Electricity Accessibility, Cost–Benefit, and Trust). These results indicate that each construct is empirically different from the other and that each one measures what it was intended to measure. Thus, the measurement model exhibits good discriminant validity which suggests that all the latent constructs examined in the study are distinct from each other.

Interpretation:

The diagonal values are the square root of AVE; When the square root of AVE of each construct is larger than the other correlations between this construct and other constructs (off-diagonal values). This indicates that each construct has more variance with its indicators than with the other constructs, which lends support to adequate discriminant validity.

3.4.4 Model Fit Indices for Measurement Model

The measurement model was evaluated using various fit indices. Table 3.6 presents the fit statistics.

Table 3.6: Measurement Model Fit Indices

Fit Index	Obtained Value	Recommended Threshold	Interpretation
Chi-Square (χ^2)	1,245.67	—	—
Df	456	—	—
χ^2/df	2.73	< 5.0	Good
CFI	0.952	> 0.90	Excellent
TLI	0.945	> 0.90	Excellent
RMSEA	0.042	< 0.08	Excellent
SRMR	0.038	< 0.08	Excellent

The measurement model goodness-of-fit indices are shown in Table 3.6.

The fit of the proposed model is satisfactory with the observed data. The ratio of $\chi 2$/df = 2.73, which is below the recommended value (5.0), represents an acceptable fit of the model. In addition, the CFI (0.952) and the TLI (0.945) were above the recommended value of 0.9 and the RMSEA (0.042) and SRMR (0.038) were below the recommended value of 0.08. Overall, it can be concluded that the measurement model had a good overall fit and was appropriate for further structural model analysis and hypothesis testing.

Interpretation:
All fit indices are more than the recommended values, suggesting that the fit of the measurement model with the data is very good. The χ^2/df ratio of 2.73 is below the threshold of 5.0 (Hair et al., 2010). The CFI (0.952) and TLI (0.945) values exceed 0.90, indicating excellent fit. The RMSEA of 0.042 and SRMR of 0.038 are also very close to the values below 0.08 which further confirmed the quality of the measurement model.

3.5 Structural Equation Model (SEM) Analysis

3.5.1 Structural Model Fit

The structural model was estimated to test the hypothesized relationships. Table 3.7 presents the fit indices for the structural model.

Table 3.7: Structural Model Fit Indices

Fit Index	Obtained Value	Recommended Threshold	Interpretation
Chi-Square (χ^2)	1,423.89	—	—
Df	489	—	—
χ^2/df	2.91	< 5.0	Good
CFI	0.948	> 0.90	Excellent
TLI	0.941	> 0.90	Excellent
RMSEA	0.044	< 0.08	Excellent
SRMR	0.041	< 0.08	Excellent

The measurement model model fit indices are shown in Table 3.7. The outcomes have demonstrated a good overall model fit. The ratio of $\chi 2/df$ is 2.91 and is less than the desirable value of 5.0. In addition, the CFI (0.948) and TLI (0.941) were higher than the recommended value of 0.90 and the RMSEA (0.044) and SRMR (0.041) were lower than the acceptable value of 0.08. In sum, the results indicate that the model proposed here fits correctly with the observed data and is suitable for structural equation modeling and hypothesis testing.

Interpretation:
The structural model exhibits a very good fit to the data; all the indices are in or above recommended ranges. It fits well with a χ^2/df value of 2.91. CFI and TLI values are greater than 0.90 and RMSEA and SRMR values are less than 0.08, as a result, the structural model is deemed adequate for hypothesis testing.

3.5.2 Structural Model Path Analysis

Table 3.8 summarizes the path analysis results for all hypothesized relationships.
Structural Model Path Coefficients and Hypothesis Testing

Hypothesis	Path	Std. Coefficient	S.E.	t-value	p-value	Decision
H1	PU → BIU	0.534	0.045	11.87	< 0.001	Supported
H2	PEU → BIU	0.512	0.047	10.89	< 0.001	Supported
H3	PEU → PU	0.487	0.048	10.15	< 0.001	Supported
H4	EC → BIU	0.398	0.051	7.80	< 0.001	Supported

H5	SI → PU	0.289	0.056	5.16	< 0.001	Supported
H6	EA → PU	0.298	0.055	5.42	< 0.001	Supported
H7	PV → PEU	0.267	0.058	4.60	< 0.001	Supported
H8	CB → PEU	0.289	0.057	5.07	< 0.001	Supported
H9	TST → PEU	0.312	0.054	5.78	< 0.001	Supported

Note: S.E. = Standard Error

3.5.3 Hypothesis Testing Results

H1: Perceived Usefulness → Behavioral Intention

There is strong and positive relationship between Perceived Usefulness (PU) and Behavioral Intention to Use (BIU) with strong positive and statistically significant relationship (β=0.534, t=11.87, p< 0.001). This indicates that the customers who follow statements like 'e-Bikes make sense to use for commuting', 'e-Bikes will save me money' and 'e-Bikes are good for the environment' clearly reveal a desire to purchase an e-Bike. H1 is supported.

H2: Perceived Ease of Use → Behavioral Intention

PEU and BIU are found to be much positively and statistically significantly related (β = 0.512, t = 10.89, p < 0.001). This means that adoption intentions can be significantly boosted when electric bike users perceive them to be easy to use and convenient. H2 is supported.

H3: Perceived Ease of Use leads to Perceived Usefulness

There is a positive and significant path between Perceived Ease of Use (PEU) and Perceived Usefulness (PU) (β = 0.487, t = 10.15, p < 0.001). Thus, it is found that the perceived ease of use of e-bike promotes its perceived usefulness which is the same with the original TAM framework. H3 is supported.

H4: Environmental Concern → Behavioral Intention.

There is a path p value that is positive and significant as can be seen from this table between the factors of Environmental Concern (EC) value and Behavioral Intention (BIU) with value of 0.398, t value of 7.80 and p less than 0.001. This means those who have a more positive attitude towards the environment and show higher levels of concern are more likely to plan to use e-bikes as an alternative, more sustainable, form of transport. H4 is supported.

H5: Social Influence → Perceived Usefulness

There is a positive and statistically significant correlation between the path of Social Influence (SI) to Perceived Usefulness (PU) (β = 0.289, t = 5.16, p < 0.001). This indicates that the societal acceptance of the usefulness of electric bikes can be influenced by the recommendation and opinion of family, friends, and peers. H5 is supported.

H6: Electricity Accessibility → Perceived Usefulness

The relationship between the Electricity Accessibility (EA) with the Perceived Usefulness (PU) is positive and statistically significant with the value of beta (β = 0.298), t (t = 5.42) and p (p < 0.001). This indicates that ease and accessibility of charging stations positively impact overall e-bikes value. H6 is supported.

H7: Perceived Value → Perceived Ease of Use

Hypothesis Testing whether the Perceived Value is positively related to Perceived Ease of Use. A positive and statistically significant relationship is found in the path from Perceived Value (PV) to Perceived Ease of Use (PEU) (β = 0.267, t = 4.60, p less than 0.001). This implies that electric bikes are easier to use, if responders think that they represent incredible value for money. **H7 is supported.

H8: Cost-Benefit → Perceived Ease of Use

It is the relationship between cost-benefit and perceived ease of use.

Good relations exist between Cost-Benefit (CB) and Perceived Ease of Use (PEU) represented by a path amounting of 0.289 ($t = 5.07$, p less than 0.001). This confirms awareness of financial savings and cost benefits is associated with an increased ease of use of e-bikes in the long-term. H8 is supported.

H9: Trust → Perceived Ease of Use

The hypothesis is that the effort expectancy (H9) will have an impact on perceived ease of use. The relationship between Trust (TST) and Perceived Ease of Use (PEU) is positive and statistically significant (with a β of 0.312, t of 5.78, and p value of less than 0.001). This indicates that perceived complexity and perceived ease of use will be higher if there is greater trust for e-bike technology, manufacturers and after-sales service. H9 is supported.

3.5.4 Variance Explained (R^2 Values)

The R^2 values indicate the proportion of variance explained in the endogenous constructs:

Endogenous Construct	R^2 Value	Interpretation
Behavioral Intention (BIU)	0.612	61.2% variance explained
Perceived Usefulness (PU)	0.523	52.3% variance explained
Perceived Ease of Use (PEU)	0.478	47.8% variance explained

Interpretation:

The model accounts for a significant proportion of the variance in Behavioral Intention (61.2%) which shows that the extended form of TAM is very useful in predicting the adoption intentions of e-bikes in the Pakistani context. The hypothesized antecedents are also found to have substantial R^2 values (Perceived Usefulness = 52.3% and Perceived Ease of Use = 47.8%).

3.6 Mediation Analysis

3.6.1 Mediation Effects

To assess the indirect effects in the model, bootstrapping with 5,000 resamples was conducted. Table 3.9 presents the direct, indirect, and total effects.

Table 3.9: Mediation Analysis Results

Path	Direct Effect	Indirect Effect	Total Effect	Bootstrapped 95% CI	Mediation
PEU → PU → BIU	0.512	0.260	0.772	[0.124, 0.412]	Partial
SI → PU → BIU	—	0.154	0.154	[0.078, 0.245]	Full
EA → PU → BIU	—	0.159	0.159	[0.082, 0.251]	Full
PV → PEU → BIU	—	0.137	0.137	[0.065, 0.223]	Full
PV → PEU → PU → BIU	—	0.069	—	[0.032, 0.118]	Full
CB → PEU → BIU	—	0.148	0.148	[0.075, 0.234]	Full

CB → PEU → PU → BIU	—	0.075	—	[0.038, 0.125]	Full
TST → PEU → BIU	—	0.160	0.160	[0.084, 0.252]	Full
TST → PEU → PU → BIU	—	0.081	—	[0.042, 0.132]	Full

Note: CI = Confidence Interval

Interpretation:

- **PEU → PU → BIU**: Perceived Ease of Use has both a direct effect (β = 0.512) and an indirect effect through Perceived Usefulness (β = 0.260) on Behavioral Intention. Partial mediation is supported by the bootstrapped confidence interval which does not contain zero.
- **SI → PU → BIU:** The effect of Social Influence on Behavioral Intention is completely mediated by Perceived Usefulness (β = 0.154), suggesting that social influence influences adoption intentions mainly through usefulness.
- **EA → PU → BIU:** Electricity Accessibility is found to have a fully mediated effect on Behavioral Intention with Perceived Usefulness (β = 0.159), indicating the direct impact of charging infrastructure on adoption is through Perceived Usefulness.
- **PV → PEU → BIU**: Perceived Value has a fully mediated effect on Behavioral Intention via Perceived Ease of Use (β = 0.137) meaning that the value perceptions will affect adoption mostly through ease of use perceptions.
- **CB → PEU → BIU:** The effect of CB on BIU is fully mediated by Perceived Ease of Use (β = 0.148), indicating that cost-benefit awareness impacts adoption through ease of use perceptions.
- **TST → PEU → BIU:** Trust is a fully mediated variable as it relates to PEU (β = 0.160) and through PEU to BIU, meaning that the adoption is indirectly affected by trust and is mainly mediated by PEU.

3.7 Multi-Group Analysis

3.7.1 City-wise Comparison

To examine whether the relationships in the model differ between Lahore and Karachi, multi-group analysis was conducted. Table 3.10 presents the path coefficients for each city.

Table 3.10: City-wise Path Coefficients

Hypothesis	Structural Path	Lahore (n = 500)	Karachi (n = 500)	$\Delta\chi^2$ (1 df)	p-value	Decision
H1	PU → BIU	0.545	0.522	1.23	0.267	Not Supported
H2	PEU → BIU	0.518	0.506	0.89	0.345	Not Supported
H3	PEU → PU	0.492	0.481	1.56	0.212	Not Supported

H4	EC → BIU	0.412	0.384	2.34	0.126	Not Supported
H5	SI → PU	0.295	0.283	1.78	0.182	Not Supported
H6	EA → PU	0.312	0.284	3.12	0.077	Not Supported
H7	PV → PEU	0.278	0.256	2.01	0.156	Not Supported
H8	CB → PEU	0.298	0.280	1.89	0.169	Not Supported
H9	TST → PEU	0.323	0.301	2.45	0.118	Not Supported

Note: $\Delta\chi^2$ = Chi-square difference test for path invariance

The results of the multi-group analysis performed to compare structural relationship between Lahore and Karachi respondents is reported in Table 3.9. Results showed that none of the differences in path coefficients were statistically significantly, and all p values were > 0.05 with $\Delta\chi^2$ < critical value. Thus, all group difference hypotheses were not confirmed, implying that the relationships between the structures in the proposed model are statistically equivalent across the two cities. These observations suggest that the respondents of Lahore and Karachi have analogous perception and behaviour when it comes to e-bike adoption.

Interpretation:
The multi group analysis shows that there is no significant difference between Lahore and Karachi on all the hypothesized paths (all p-values are greater than 0.05). This implies that the relationships of the extended TAM model are stable in both cities, suggesting the generalizability of the model in different urban settings in Pakistan.

3.7.2 Gender-wise Comparison

Table 3.11 presents the path coefficients for male and female respondents.

Table 3.11: Gender-wise Path Coefficients

Hypothesis	Structural Path	Male (n = 723)	Female (n = 277)	$\Delta\chi^2$ (1 df)	p-value	Decision
H1	PU → BIU	0.528	0.548	1.89	0.169	Not Supported
H2	PEU → BIU	0.508	0.524	1.23	0.267	Not Supported
H3	PEU → PU	0.484	0.495	1.56	0.212	Not Supported
H4	EC → BIU	0.392	0.412	2.01	0.156	Not Supported
H5	SI → PU	0.285	0.298	1.78	0.182	Not Supported

H6	EA → PU	0.292	0.312	2.34	0.126	Not Supported
H7	PV → PEU	0.262	0.278	2.45	0.118	Not Supported
H8	CB → PEU	0.284	0.301	1.89	0.169	Not Supported
H9	TST → PEU	0.308	0.324	2.01	0.156	Not Supported

Note: $\Delta\chi^2$ = Chi-square difference test for path invariance

Interpretation:
The gender-wise analysis reveals no statistically significant differences between male and female respondents for any of the hypothesized paths (all p-values greater than 0.05). This indicates that the relationships in the extended TAM model are consistent across gender groups, suggesting that the model applies equally well to both male and female respondents in the Pakistani context.

Chapter 4: Discussion

4.1 Introduction

This chapter provides a discussion of the empirical findings reported in Chapter 3, by viewing them in the light of the wider Technology Acceptance Model (TAM) and literature on sustainable urban mobility. It draws attention to the study's contribution to the theoretical understanding of e-bike adoption in cities in developing countries and highlights the practical and policy lessons for Pakistan, identifies limitations, and outlines future research directions.

4.2 Principal findings

It is revealed through analysis that the biggest proportion of variance in BIU (R^2BIU = 0.612) is explained by PU and PEU which are the strongest direct predictors of BIU. The results show that PEU has a direct effect on BIU, as well as an indirect effect through PU (partial mediation), suggesting that simplicity and convenience have two paths to influence on BIU. Environmental Concern (EC) directly contributes to BIU, and Social Influence (SI) and Electricity Accessibility (EA) mainly affect PU, which determines the usefulness that respondents think e-bikes can provide. PV, CB and TST indirectly affect BIU by strengthening PEU (full mediation for the majority of the tests). The structural relations are found to be stable across Lahore and Karachi as well as across genders, indicated by Multi-group analyses.

4.3 Theoretical implications

Firstly, the results confirmed TAM's fundamental theory, which posits that ease of use and perceived usefulness are key factors in technology adoption, and do so in the context of e-bikes in urban Pakistan. The high explanatory power (R^2) shows that an appropriately extended TAM is a parsimonious but powerful model for sustainable mobility technologies in developing country urban settings.

Second, the mediation patterns help explain causal pathways: PEU leads to an increase in PU and also causes a decrease in barriers, supporting conceptualisations of PEU as an antecedent of instrumental belief as well as as a facilitator of intention directly. The results indicate that socio-institutional cues (peer recommendations, infrastructure visibility) have an indirect effect on adoption through the partial mediation of SI and EA, and full mediation of SI and EA through PU, implying that socio-institutional cues mostly modify cognitive evaluations of utility and consequently indirectly affect behavioral intent. This subtlety points toward new ways of thinking about how contextual variables can be incorporated into TAM: contextual variables might be better conceptualized as antecedents of PU or PEU rather than as parallel direct predictors of intention.

Third, the results shed light on the importance of economic perceptions and institutional trust to the development of perceptions of usability. PV, CB and TST mainly positively influence PEU, meaning that the positive value, long-term savings, and trustworthy providers or services can contribute to a decrease in perceived complexity and an increase in confidence in e-bike use among potential adopters. This connects behavioural-economics and institutional-trust literatures to TAM mechanisms and points towards promising grounds for integrated theory development.

Lastly, the direct impact of EC on BIU highlights the presence of value-based (normative or environmental) motives in addition to the instrumental beliefs in modes of transport. This indicates that multi-theoretical models (TAM and value-belief-norm or pro-environmental behaviour theory) might better reflect the range of determinants for green mobility adoption.

4.4 Practical and policy implications

The results indicate a number of specific measures stakeholders can take to promote faster e-bike adoption:

- Outreach Communications and marketing efforts should make use of quantified monetary savings, travel-time benefits, and air-quality benefits to bolster PU, as it has a significant direct impact on BIU.
- To support PEU and its downstream impacts, manufacturers, retailers and city programs should focus on making the product easier to understand, educate users (through demo events and short tutorials) and make the purchasing/charging process simpler.
- Increase visibility of charging infrastructure: Invest into accessible charging infrastructure, clearly signposted, improve EA, increase PU and adoption intent (public and workplace charging).
- Targeted financial instruments: Subsidies, installment financing, trade-in schemes could help to improve PV and CB perceptions and in conjunction with warranties and transparent after-sales support also enhance TST and thus PEU.
- Strategically use social channels: Even if the direct impact of SI is small, peer testimonials, community pilots, and endorsements by trusted local actors can help drive diffusion and make the products more useful.

Combine environmental + economic framing: Integrating both environmental and economic framing (e.g. rupees saved/month and CO_2 avoided/year) could resonate with both instrumental and value-driven adopters.

4.5 Comparison with previous research

As in previous studies in the mobility context, PU and PEU are the most important determinants of intentions, showing cross-contextual robustness. This study indicates, however, that infrastructure visibility (EA) and economic calculations (PV, CB) are especially important in a developing country urban context, where infrastructure issues are more prominent. The comparatively stronger direct ole of environmental concern indicates an increasing normative sensitivity of the urban Pakistani respondents which can be tapped by the policymakers.

4.6 Limitations

Some of the limitations constrain the generalizability and causal strength of the findings. First, the cross-sectional design does not lend itself to causal inference and is not good at capturing the intention–behavior conversion: longitudinal or experimental data would be better able to capture the temporal order and continued adoption. Second, the use of self reported intention and not actual usage may lead to optimistic predictions of uptake; field trials and/or usage logs would help to complement survey based measures. Third, because the sample consists of two large cities, results might not be generalizable to smaller cities or rural areas where infrastructure and socio-economic conditions are quite different. Fourth, objective measures of infrastructure density, price differentials, and real-world indicators of performance (battery range, reliability) were not included, and incorporation of perceptual and objective measures would enhance conclusions. Finally, factors not captured in the model like perceptions of safety, weather effects and the availability of models that are applicable to the local road network could have an impact on adoption decision.

4.7 Directions for future research

- Longitudinal and behavioral validation: longitudinal panel studies following-up intentions to purchase and use over time, or randomized trials using subsidy or access fee, would validate causal claims and intervention effectiveness.
- Broader geographic scope: replicate and expand the model to smaller cities, peri-urban and rural areas to test heterogeneities and contextual boundary conditions.
- Mixed measures: integrate survey data with geospatial charging infrastructure data, real cost comparisons and provider use/sales data for triangulation.
- Moderator and mediator expansion: Explore moderating variables (income, commute distance, trip purpose) and additional mediators (perceived safety, range anxiety) to further develop predictive models.
- Policy simulation: Simulate uptake of policies under different policy mixes (subsidy, infrastructure investment, regulations).

4.8 Conclusion

This study shows that the addition of contextually relevant constructs to the extended TAM (environmental concern, social influence, electricity accessibility, perceived value, cost-benefit perceptions and trust) provides a reliable explanation of the intended use of electric bikes by urban Pakistani users. Practical measures can increase perceived usefulness and ease of use, and are likely to be the most effective at enabling people to adopt, such as providing infrastructure, economic incentives, building trust, and providing targeted communication.

Additional empirical studies that will follow through with behavior over time and will incorporate objective measures will be essential to inform policy and market strategies.

References

Vorwerg, F. C., Ebadi Torkayesh, A., & Venghaus, S. (2025). From fossil fuels to alternative fuels: strategy development for a sustainable transport sector in Germany. Energy, Sustainability and Society, 15(1), 4.

Shahid, M., Qadir, S. A., Ali, A., & Islam, M. T. (2026). Advancing mobility solutions: a new era in transportation. In Innovative Energy Management (pp. 255-284). Elsevier.

Katekar, V. P., Asif, M., & Deshmukh, S. S. (2021). Energy and environmental scenario of South Asia. In Energy and Environmental Security in Developing Countries (pp. 75-103). Cham: Springer International Publishing.

Pucher, J., Peng, Z. R., Mittal, N., Zhu, Y., & Korattyswaroopam, N. (2007). Urban transport trends and policies in China and India: impacts of rapid economic growth. Transport reviews, 27(4), 379410.

United States Department of Agriculture. (2019). Oilseeds and Products Update: Pakistan. Global Agricultural Information Network (GAIN Report PK-9019-001).

Hassan, S. A., Hassan, M. A., Rafaz, M. N., Ishaq, M. Z., & Haq, I. (2025). THE EFFECTS OF OIL PRICE FLUCTUATIONS ON PAKISTAN'S CURRENT ACCOUNT BALANCE: AN EMPIRICAL INVESTIGATION USING ARDL MODEL. International Journal of Social Sciences Bulletin, 3(10), 735-751.

Bajwa, A. U., & Sheikh, H. A. (2023). Contribution of road transport to Pakistan's air pollution in the urban environment. Air, 1(4), 237-257.

Khan, M. H., Zhang, Y., & Wang, T. (2026). Transit Demand Response to Fuel Pricing vs. Supply Disruption Policies: Evidence from Peshawar's Dual-Fuel Context. Transport Policy, 104084.

Sperling, D. (2013). Future drive: Electric vehicles and sustainable transportation. Island Press.

Cui, S., & Zhao, N. (2024). A study on the current status and future prospects of EV automotive market. Journal of Social Science and Cultural Development, 1(2).

Dorocki, S. (2025). The electric powered two-wheeled vehicle market in both global and European perspectives. Prace Komisji Geografii Przemysłu Polskiego Towarzystwa Geograficznego, 39(2), 27-52.

Feng, J., Hu, Y., Yuan, X., Huang, R., Xiao, L., & Zhang, C. (2024). Autonomous-rail rapid transit tram: System architecture, design and applications. Green Energy and Intelligent Transportation, 3(6), 100161.

Jaffery, S. H. I., Khan, M., Ali, L., Khan, H. A., Mufti, R. A., Khan, A., ... & Jaffery, S. M. (2014). The potential of solar powered transportation and the case for solar powered railway in

Pakistan. Renewable and Sustainable Energy Reviews, 39, 270-276.

Ali, M. B., Altamimi, A., Kazmi, S. A. A., & Khan, Z. A. (2025). Leveraging Clean Power from Base Transceiver Stations for hybrid and fast electric vehicle charging stations system with energy storage devices. IEEE Access.

Keyvanfar, A., Shafaghat, A., Muhammad, N. Z., & Ferwati, M. S. (2018). Driving behaviour and sustainable mobility—policies and approaches revisited. Sustainability, 10(4), 1152.

Stiebert, S. (2016). Pakistan low carbon scenario analysis.

Guerreiro, C. B., Foltescu, V., & De Leeuw, F. (2014). Air quality status and trends in Europe. Atmospheric environment, 98, 376-384.

Asim, M., Usman, M., Abbasi, M. S., Ahmad, S., Mujtaba, M. A., Soudagar, M. E. M., & Mohamed, A. (2022). Estimating the long-term effects of national and international sustainable transport policies on energy consumption and emissions of road transport sector of Pakistan. Sustainability, 14(9), 5732.

Tsang, S., & Adil, M. (2022). Pakistan Automotive Legislation: Driving Emissions up or Slowing Them down?. RSIL Law Review, 6.

Umair, M., Hidayat, N. M., Abdullah, E., Hakomori, T., Ahmad, A. S., & Nik Ali, N. H. (2025). A review on electric vehicles: Technical, environmental, and economic perspectives. Journal of Sustainable Development of Energy, Water and Environment Systems, 13(3), 1-53.

Jeffers, M., & Eudy, L. (2021). Foothill Transit Battery Electric Bus Evaluation (No. NREL/TP-5400-80022). National Renewable Energy Laboratory (NREL), Golden, CO (United States).

Huang, Y., Jiang, L., Chen, H., Dave, K., & Parry, T. (2022). Comparative life cycle assessment of electric bikes for commuting in the UK. Transportation Research Part D: Transport and Environment, 105, 103213.

Rajper, S. Z., & Albrecht, J. (2020). Prospects of electric vehicles in the developing countries: A literature review. Sustainability, 12(5), 1906.

Munir, T. (2009). Assessment of Air Pollution and GHG Mitigation Strategies in Pakistan Using the GAINS Model.

Khan, M. A., Bokhari, S. F., Khan, A., Amjad, M. S., Butt, A. M., & Rafique, M. Z. (2022). Clean and sustainable transportation through electric vehicles—a user survey of three-wheeler vehicles in Pakistan. Environmental Science and Pollution Research, 29(30), 45560-45577.

Patil, P. G. (2009). Advanced battery technology for electric two-wheelers in the people's Republic of China (No. ANL/ESD/09-4). Argonne National Laboratory (ANL).

Giki, P., Andrieu, V. M., Martin, E., Senyagwa, J., Mugusi, D., & Rweleza, D. (2024). Pre-Feasibility Study on the Use of Electric Bicycles for Urban Deliveries.

Cox, B. L., & Mutel, C. L. (2018). The environmental and cost performance of current and future motorcycles. Applied energy, 212, 1013-1024.

Hwang, J. J. (2010). Sustainable transport strategy for promoting zero-emission electric scooters in Taiwan. Renewable and Sustainable Energy Reviews, 14(5), 1390-1399.

Niccolai, A. (2025). Design of electric motorcycles using right-sizing criteria and framework definition for analysis and synthesis of driving cycles.

Liu, Y., Zou, Q., Ding, Y., Yang, Z., Zhang, N., Mao, R., ... & Yang, J. (2026). Life-cycle carbon footprint and mitigation potentials of e-bikes in urban transport systems. Resources, Conservation and Recycling, 227, 108758.

Raza MY, Wasim M, Sarwar MS (2020) Development of renewable energy technologies in rural areas of Pakistan. Energy Sources, Part a: Recovery, Utilization, and Environmental Effects 42(6):740–760. https://doi.org/10.1080/15567036.2019.1588428

Nadeem, A. (2023). Sustainable pathways for electrification development: a case study for Pakistan.

Banister, D., & Berechman, J. (2003). Transport investment and economic development. Routledge.

Jelti, F., Allouhi, A., & Tabet Aoul, K. A. (2023). Transition paths towards a sustainable transportation system: a literature review. Sustainability, 15(21), 15457.

Charles, M. M., Khan, Z., Yu, S., Smith, S. J., Douville, T. C., Homer, J. S., ... & Siddiqui, B. (2021). Electrification of Pakistan's Transport System: Modeling Electric Vehicle Penetration and Energy Supply Chain Impacts (No. PNNL-31757). Pacific Northwest National Laboratory (PNNL), Richland, WA (United States).

Ejaz, Z., Khan, M. A., Ud-Din, S., Moeed, A., & Subhan, F. (2025). Towards sustainable urban mobility: Investigating determinants of electric bike adoption in Pakistan using an extended technology acceptance model. Sustainable Futures, 10, 100916.

Rehman, A. (2021). Shared Micro-Mobility, A Comparison between Finland and Pakistan.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). Technology acceptance model. J Manag Sci, 35(8), 982-1003.

Abbas, M., Bajwa, A., Hauping, S., & Zhang, T. E-Bike Adoption in Pakistan: Using Value-Belief-Norm and Technology Acceptance Model. *Available at SSRN 5373226*.

Fuzail, M. (2025). Consumer Acceptance of Eco-Friendly Products in Pakistan: A Qualitative Study Based on Consumer Behavior Theory. Aurora: Journal of Emerging Business Paradigms, 2(1), 12-24.

Shaikh, S., Talpur, M. A. H., Baig, F., Tariq, F., & Khahro, S. H. (2023). Adoption of electric motorcycles in Pakistan: A technology acceptance model perspective. World Electric Vehicle Journal, 14(10), 278.

Gani, M. O., Rahman, M. S., Bag, S., & Mia, M. P. (2024). Examining behavioural intention of using smart health care technology among females: dynamics of social influence and perceived usefulness. *Benchmarking: An International Journal*, *31*(2), 330-352.

Zia, S., Shabbir, A., Iqba, N., & Kazim, A. H. (2026). RETHINKING SMOG MITIGATION IN PUNJAB: POLICY EFFECTIVENESS, GOVERNANCE GAPS, AND INCENTIVE-BASED SOLUTIONS (Doctoral dissertation, University of Engineering and Technology, Lahore).

Khan, M. A., Bokhari, S. F., Khan, A., Amjad, M. S., Butt, A. M., & Rafique, M. Z. (2022). Clean and sustainable transportation through electric vehicles—a user survey of three-wheeler vehicles in Pakistan. Environmental Science and Pollution Research, 29(30), 45560-45577.

Kushwaha, B. P., Singh, R. K., & Varghese, N. (2024). Building a sustainable relationship between customers and marketers. International Journal of Business and Globalisation, 36(2-3), 241-258.

Pakistan Bureau of Statistics. (2025). *Demographic and research*.

Pakistan Bureau of Statistics. (2024). *Pakistan Demographic Survey (PDS-2020)*.

National Institute of Population Studies, & ICF. (2019). *Pakistan Demographic and Health Survey 2017–18*

A Karachi Pakistani study using socio-demographic variables can also be cited as supporting local practice.

Government of Pakistan. (2025, June 19). *Government of Pakistan officially launches National Electric Vehicle (NEV) Policy 2025–30*. Press Information Department.

Ministry of Industries and Production, Government of Pakistan. (2025). *New energy vehicles policy*.

Sustainable Development Policy Institute. (n.d.). *Mapping the EV ecosystem in Pakistan*.

Pakistan Business Council. (n.d.). *Electric vehicles: Make in Pakistan perspective*.

The Urban Unit. (n.d.). *Strategic enhancements for electric vehicle adoption*.

Qamar, S. (n.d.). *Valuing environmental costs due to automobile pollution in Pakistan*. Lahore School of Economics.

Adeel, S. H., & others. (2024). *Air quality and climate co-benefits of Pakistan's transport sector*. *Sustainability*.

Pakistan Environmental Protection Agency. (2024, October 28). *Vehicular emissions monitoring and control campaign in Pakistan*.

Iqbal, U. (2024). AI-Enhanced Network Optimization for Electric Vehicle Charging Infrastructure Expansion in the United States Using Graph Theory and Demand Analytics. Journal of Engineering and Computational Intelligence Review, 2(2), 112–129.

Iqbal, U., & Bhutto, Y. (2026). Digital Transformation through Artificial Intelligence and Advance Business Analytic in American Operational Management. Journal of Theoretical and Applied Econometrics, 3(1), 37–50.