Pre-Feasibility Assessment on Electric Buses in Siem Reap, Cambodia

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Chapter 4 of this Pre-feasibility Assessment report draws upon the work and methodologies of Dr. Jurg Grutter for GGGI on Low Carbon Buses for Amman, Jordan.

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List of Abbreviations

AC	Alternating Current
APSARA	Authority for the Protection of the Site and Management of the Region of Angkor
ATMS	Advanced Traffic Management System
BC	Black Carbon
BEB	Battery-powered Electric Bus
BIS	Bus Information System
BIT	Bus Information Terminal
BRT	Bus Rapid Transit
CAPEX	Capital Expenditure
CBD	Central Business District
CH4	Methane
CO2	Carbon Dioxide (CO2)
DC	Direct Current
DUPT	Department of Urban Public Transport
E-bus	Electric Bus
ED	Electricite Du Cambodge
EIRR	Economic Internal Rate of Return
ENPV	Economic Net Present Value
FIRR	Financial Internal Rate of Return
FNPV	Financial Net Present Value
GCF	Green Climate Fund
GDLT	General Director Department of Land Transport
GGGI	Global Green Growth Institute
GHG	Greenhouse Gas
HFCs	Hydrofluorocarbons
ICE	Internal Combustion-Engine

IPES	Illegal Parking Enforcement System
IPT	Inductive Power Transfer
ITS	Intelligent Transport System
JICA	Japan International Cooperation Agency
Km	Kilometers
kWh	Kilowatt hour
kW	Kilowatt
kVA	Kilovolt-ampere
MAC	Marginal Abatement Cost
MPWT	The Ministry of Public Works and Transport
NCSD	National Council for Sustainable Development
NOx	Nitrogen Oxides
N2O	Nitrogen Oxide
NF3	Trifluoride Nitrogen
OBE	In-vehicle Terminal
OLEV	Online Electric Vehicle
OPEX	Operational Expenditure
PFCs	Perfluorocarbons
PM	Particulate Matter
PMS	Parking Management System
RGC	Royal Government of Cambodia
SF6	Sulfur Hexafluoride
TCO	Total Cost of Ownership
TTW	Tank-to-Wheel
USD	United States Dollars
UNFCCC	United Nations Framework Convention on Climate Change
VDS	Vehicle Detection Sensors
VMS	Variable Message Systems
WACC	Weighted Average Cost of Capital

WTT	Well-to-Tank
WTW	Well-to-Wheel

Executive Summary

Siem Reap is the second largest city and the most popular tourist destination in Cambodia and is home to the World Heritage Site of Angkor Wat. Increasing tourist numbers (pre-COVID-19) have generated negative environmental impacts including greenhouse gas (GHG) emissions and traffic congestion. As a result, there is now a need to consider introducing a range of mitigation measures which include sustainable and smart transport systems such as electric public buses.

Further to a request by the Department of Urban Public Transport (DUPT), this study assesses the technical, environmental, and financial feasibility of introducing three new bus lines as a pilot project using low carbon vehicles. These three pilot bus lines, as suggested by the DUPT, are shown in the below figure.

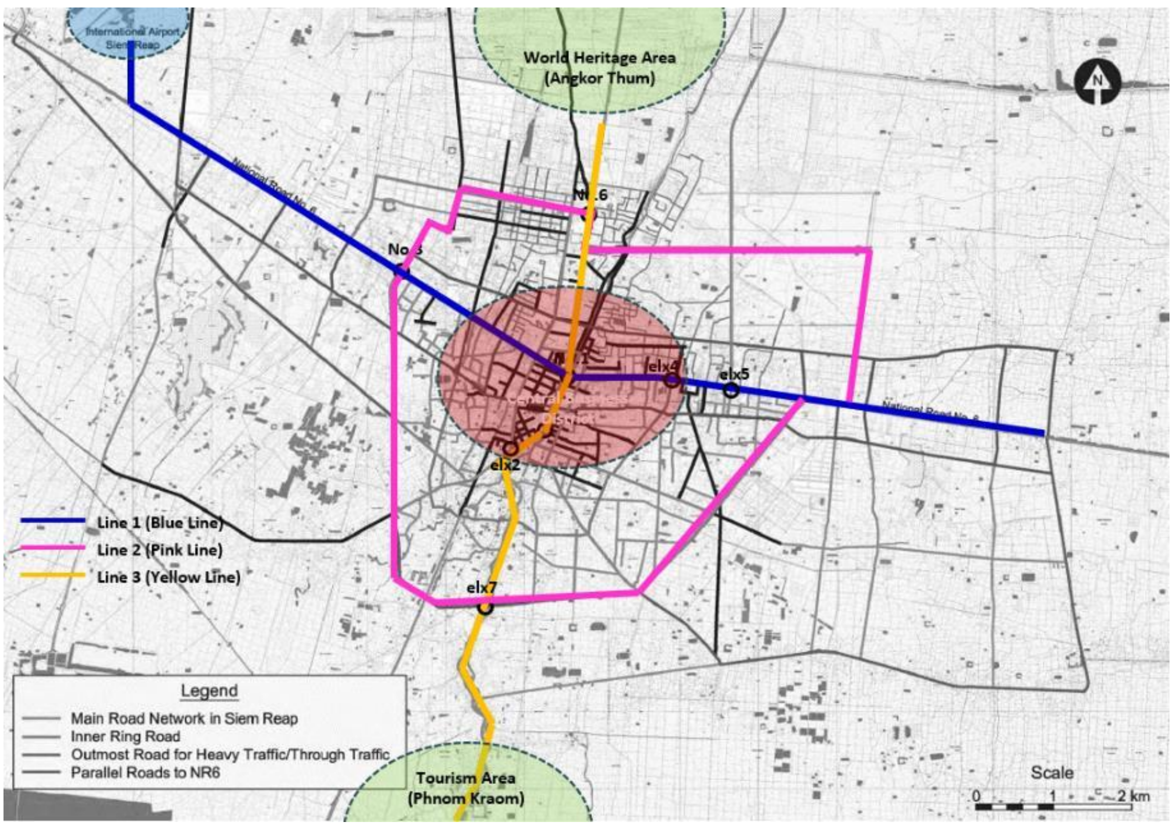


Figure 1: Map of Proposed 3 Lines in Siem Reap

- Line 1 (Blue) is National Road No. 6 connecting Siem Reap airport to the city center area, playing an important role in meeting tourist demands.
- Line 2 (Pink) is a ring road running adjacent to the city center, the Central Business District (CBD) fringe, and the Authority for the Protection of the Site and Management of the Region of Angkor (APSARA) cultural/tourism zone. The line is also assigned as a Siem Reap Bypass

Road, leading heavy vehicles to the bypass instead of entering Siem Reap city via National Road No. 6.

- Line 3 (Yellow) will be utilized as a service road linking the CBD and the World Heritage Site areas, including Angkor Thom and Phnom Kraom, thus formulating a semi-urban structure as a service town of the World Heritage Site but also as a key tourist destination in and of itself.

Key findings from the traffic volume survey by GGGI are as below. It should be noted that the traffic volume during the survey period (February 5-6, 2021) was significantly lower than the previous year due to the preventative restrictions imposed in response to the COVID-19 pandemic and construction work on National Road No. 38. It is therefore recommended that the survey result is only considered indicative.

- The traffic volume of Line 1 on weekdays was about 47,000 units and was found to be the busiest among the analyzed routes.
- In terms of modal share on Line 2 on weekdays, it clearly showed that motorcycles are the dominant mode of transportation, accounting for approximately 69.5%, followed by passenger cars (16.9%), and heavy vehicles (13.6%).
- Variation of traffic volume on Line 3 was greater than that of the other two lines.

Table 1: Traffic Volume of the Proposed 3 Lines

Vehicle Type		Line 1		Line 2		Line 3	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Passenger Car	Units	10,943	9,953	1,017	1,767	3,512	4,147
	%	23.1%	23.4%	16.9%	17.8%	16.6%	19.2%
Bus	Units	810	759	76	49	800	230
	%	1.7%	1.8%	1.3%	0.5%	3.8%	1.1%
Truck	Units	942	816	741	735	917	363
	%	2.0%	1.9%	12.3%	7.4%	4.3%	1.7%
Motorcycle	Units	34,607	31,042	4,179	7,349	15,975	16,836
	%	73.2%	72.9%	69.5%	74.2%	75.3%	78.0%
Total	Units	47,301	42,569	6,012	9,899	21,203	21,576
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The GGGI satisfaction survey, covering a core sample of 240 citizens in Siem Reap, identified that the major transport problems faced by citizens in Siem Reap were traffic congestion, lack of traffic information (such as information on congestion, construction, and accidents), and lack of parking spaces. Problems arising in transport services are the absence/accuracy of service information, irregular service, and lack of facilities and services.

To address traffic and environmental issues and enhance transport services in Siem Reap, the introduction of low-carbon buses (electric buses) and smart bus management systems is proposed.

This study provides a technical analysis of different low-carbon buses and smart transport system options as well as a comprehensive investment comparison analysis between the diesel baseline and the low-carbon technology option in the Siem Reap context.

The study reviewed a range of e-bus technology options and recommends 12-meter-long battery-powered electric buses (BEB) with a plug charging system as being optimal for the proposed three lines in Siem Reap, considering the local conditions, e.g., low traffic demand with less than 200 kilometers (km) in daily distance driven, and economic aspects (lower infrastructure cost).

Siem Reap bus operation services are planned based on the information provided by DUPT as below:

Table 2: Siem Reap Bus Operation Plan

Parameter	Unit	Route 1	Route 2	Route 3	Total
Route length	km	13.66	20.32	15.05	49.03
Headway bus	minutes	10	14	10	
Average speed	km/h	19	19	19	
Stand time per side	minutes	6	6	6	
Cycle time	minutes	98	140	107	
Reserve buses	percentage	10%	10%	10%	
Fleet required at peak time	buses	10	10	10	30
Fleet including reserve units	buses	11	11	11	33
Passenger capacity 12 meter (m) bus	passengers	80	80	80	
Annual distance driven per buses	km	90,000	90,000	90,000	

Estimated capital expenditure (CAPEX) and operational expenditure (OPEX) for e-bus services in Siem Reap are as per the below table. It should be noted that the costs are calculated based on the global data currently available online, and CAPEX is expected to decrease with the development of improved technology. A detailed cost estimation will be required at a later stage reflecting local conditions.

Table 3: Cost Estimation for E-buses in Siem Reap (unit: thousand USD)

Item	Cost	Note
CAPEX Bus	11,224	33 e-buses (including reserve) * $340K per bus
CAPEX Charging Station	594	1 slow charger ($6,000) per bus, 0.2 rapid charger ($60,000) per bus
CAPEX Total	11,818	
CAPEX Battery Replacement (Y9)	136	Battery lifespan = 8 years
OPEX Electricity cost	579	0.15USD/kwh*90,000km*1.3Kwh/km (per bus)
OPEX Maintenance cost	475	0.2 USD/km*90,000km*80% (per bus)
OPEX Total (annual)	1,054	

Table 4 below shows the expected environmental impact of the electric fleet (BEB) per annum and over the lifetime of the buses in comparison to the diesel baseline. Overall carbon dioxide (CO_2) emissions including black carbon are reduced by 43%, and Particulate Matter ($PM_{2.5}$) and Nitrogen Oxides (NO_x) emissions are reduced by 100%. In addition, the introduction of electric buses will decrease reliance on imported fossil fuels and build the image of Siem Reap as an electric mobility leader in the region.

Table 4: Environmental Impact of BEB buses (Unit: USD tons)

Emissions per Annum	Diesel		BEB		BEB reduction		
	Per line	3 lines	Per line	3 lines	%	Per annum	lifespan
CO2 emissions TTW (Tank-to-Wheel) direct	1,225	3,674	-	-	100%	3,674	58,785
CO2 emissions WTT (Well-to-Tank) incl. BC_indirect	356	1,069	901	2,703			
CO2 emissions WTW (Well-to-Wheel) incl. BC_combined	1,581	4,743	901	2,703	43%	2,040	32,645
PM2.5 emissions	0.1	0.3	-	-	100%	0.3	5
NOx emissions	7	21	-	-	100%	21	331

The financial assessment is conducted to compare incremental costs and savings of e-buses with those of diesel vehicles, while the economic assessment is carried out from the perspective of the entire economy and evaluating projects against overall economic benefits, e.g., emissions reductions into society.

Table 5 below shows that although the BEB option would require additional capital expenditures compared to diesel vehicles, operating a fleet of e-buses is financially and economically more attractive over the lifespan, presenting a positive financial net present value (approximately USD 2 million in total cost savings) and an economic net present value (approximately USD 3.3 million net economic benefits).[1] In other words, total cost of ownership (TCO) of the BEB option is lower than diesel in the Siem Reap context, because OPEX savings are high, due to significant cost savings during operation.

Table 5: Key Result of Financial and Economic Assessments (Unit: USD thousand)

Item	Diesel	BEB
CAPEX bus (inc. 1 time battery replacement)	6,427	11,333
CAPEX bus infrastructure	0	594

[1] FNPV presents if the incremental investment cost is recovered by savings from OPEX using WACC as a discount value of 10.3% (cost of invested capital). ENPV includes economic costs or savings related to reduction of GHGs, PM and NO_x in the analysis, and is calculated using a social discount rate of 9.0%.

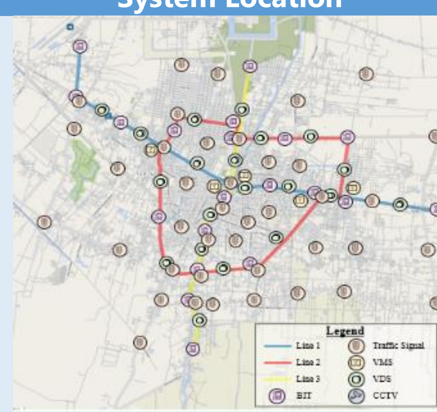
Incremental total CAPEX	5,501
OPEX savings year per annum	1,011
Economic savings per annum	96
Financial net present value (FNPV)	1,991
Economic net present value (ENPV)	3,298
Financial internal rate of return (FIRR)	17%
Economic internal rate of return (EIRR)	20%
Marginal Abatement Cost (MAC) per tCO_2 non-discounted/discounted (WTW)	-65/-321 USD

The study recommends further work to analyze the feasibility of introducing a traffic signal system and an Advanced Traffic Management System (ATMS), to improve the provision of traffic information and alleviate traffic congestion. Traffic congestion in Siem Reap could be alleviated by providing a bypass route through ATMS and interlocking traffic signals. A Parking Management System (PMS) may help to solve the parking problem raised in the satisfaction survey by reducing illegal parking and efficiently securing parking spaces. By providing bus information to citizens through a Bus Information System (BIS), user satisfaction could be improved, and demand for public transport services could be increased. Currently degraded bus facilities can be resolved by providing bus shelters and introducing e-buses.

In consideration of the current transport conditions, the study suggests considering instituting Intelligent Transport System (ITS) services on a step-by-step basis as follows:

- **Phase 1**: Advanced Traffic Management System (ATMS), Bus Information System (BIS), Bus Management System (BMS)
- **Phase 2**: Illegal Parking Enforcement System (IPES), Parking Management System (PMS)

Table 6: Deployment Plan of Transport Management Systems

System	Component	No.	Unit	System Location
Center	H/W	1	set	
	S/W	1	set	
	N/W	1	set	
	Interior	1	set	
BIS/ BMS	Bus Information Terminal (BIT)	20	ea.	
	In-vehicle terminal (OBE)	500	ea.	
ATMS	Traffic Signal	40	ea.	
	Variable message systems (VMS)	5	ea.	
	Vehicle detection sensors (VDS)	20	ea.	

	Close Circuit Television (CCTV)	5	ea.	

A quick assessment of Siem Reap City over multiple enabling factors for introducing e-bus systems such as public transport, environmental policy, energy and infrastructure, governance and regulation, and funding and financing revealed that the city has a weak base in most of these factors. The successful introduction and operation of an e-bus system will require rigorous environmental commitments/targets on a national/municipal level, relevant regulations and emission standards, a stable supply of and easy access to electricity, and solid institutional arrangement for the introduction, operation, and supervision of an e-bus system, as well as effective coordination among diverse stakeholders.

The report discusses potential risks associated with the project and mitigation strategies, including a negative impact on local jobs in the transport sector (mainly tuk-tuk drivers); a lack of institutional and technical capacity for e-bus operation; passenger demand-based risk for the suggested bus lines; the environmental impact of used battery waste; the availability of land for an e-bus depot/terminal; and the impact on the grid.

The most common method for financing e-buses is self-financing combined with grants from central and local government. As the e-bus option has a higher initial CAPEX but lower OPEX, a leasing scheme could be effective in reducing the substantial upfront cost for purchasing e-buses, while enabling the authority to use OPEX savings to make long-term lease payments. Introducing the lease option would require a shift in the conventional procurement decision method from being CAPEX-driven towards a comparison of total costs of ownership.

Public agencies in the relevant sector such as the Electricite Du Cambodge (EDC) can be considered as potential investors, in particular for charging infrastructure, as EDC will benefit from the e-bus program and overall electrification of vehicles in the country. Also, concessional finance from global/regional climate funds, development banks, and donors can be sought to cover part of the project costs, especially for incremental CAPEX and/or costs for charging infrastructure.

Chapter 1: Introduction

1.1 Project Background

Global Green Growth Institute (GGGI) has been supporting the Royal Government of Cambodia (RGC) to promote green mobility through the deployment of e-motorcycles under the Green Climate Fund (GCF) readiness project, recognizing that the transport sector is expected to have the largest increase and share of GHG emissions by 2050 in the country. The Ministry of Public Works and Transport (MPWT) has requested GGGI to provide additional support in the e-mobility sector to assess the feasibility of introducing clean buses in Siem Reap, based on GGGI's experience in assessing the feasibility of introducing low carbon bus options for Nepal, Jordan, and Lao PDR.

The Agreement between the General Director Department of Land Transport (GDLT) and GGGI to support the implementation of a "Pre-Feasibility Assessment on Electric Buses in Siem Reap" as an investment project under the Department of Urban Public Transport ("the Agreement") was signed on 29 January 2021 after a meeting between the Department of Urban Public Transport (DUPT) and GGGI. Under the Agreement, GGGI has carried out the Pre-Feasibility Assessment, while the GDLT has provided strategic oversight and supported institutional coordination with relevant authorities and stakeholders. DUPT has provided the basic information on the three bus lines for analysis by GGGI based on its "Feasibility study on Public Bus Transportation in Siem Reap" conducted in 2019-2020. The joint mission trip by GGGI and DUPT to Siem Reap city took place on 1-7 February 2021 for the purpose of consultation with the relevant authorities and stakeholders at provincial and municipal levels, collecting local data, and conducting a traffic and satisfaction survey at the project site.

Siem Reap is the second largest city in Cambodia and thanks to being home to the World Heritage Site of Angkor, is the most popular tourist destination in the Kingdom of Cambodia. The unique historical and cultural heritage in Siem Reap and the Angkor Area makes it one of the world's most significant historical and cultural tourist destinations. Although tourism numbers have seen a significant downturn due to the impact of COVID-19 pandemic and travel restrictions, increased tourist visits pre-COVID-19 have generated negative environmental impacts on both local communities and monuments. The level of these impacts requires the introduction of a range of mitigation measures including sustainable transport services such as electric public buses and smart transport systems.

The outcome of the GGGI assessment will inform the decision-making of the Cambodia government in introducing the first public bus system in Siem Reap. It is expected that a clean, effective public bus system will not only help the smart and sustainable development of the city by reducing overall GHG emissions, air pollution, and traffic congestion, but also contribute to improving its clean image to the wider local and visiting population. The planned bus lines will play a pivotal role in this perception given that the routes will connect to the World Heritage Site of Angkor which welcomed 2.6 million tourists annually pre-COVID-19.

1.2 Project Purpose and Scope

1.2.1 Purpose

The overall objective of this report is to support integrated, sustainable, and innovative low-carbon transport in Siem Reap City. This report will make policy and investment recommendations regarding the introduction of e-buses and provide a detailed plan for consideration for an Intelligent Transport System (ITS) in Siem Reap. The specific objectives of the report are as follows:

- To understand the current transport condition in Siem Reap, conduct transport analysis activities including traffic volume, a speed assessment, and a transport satisfaction survey;
- To assess the technical, environmental, financial, economic, and operational viability of introducing low-carbon public bus systems;
- To formulate initial considerations regarding options for ITS to be investigated;
- To identify cost-effective solutions to enhance the connectivity to every major tourist destination of the Angkor World Heritage Site, the Tonle Sap Lake area, and other urban tourism destinations.
- To ensure urban efficiency through improved urban transport management and low-carbon public transport mobility.

1.2.2 Scope

This report determines the technical, environmental, financial, and operational viability of introducing electric buses and formulates initial considerations around smart transport management technologies in Siem Reap. The scope of work encompasses relevant transport data collection, assessment of technology options and the recommendation of appropriate solutions. The study mainly focused on different low-carbon technology options including electric buses and smart transport systems. In terms of e-buses, it analyzed a diverse set of electric bus options and assessed the incremental costs and benefits of introducing the selected e-bus option compared to the baseline diesel option. Based on the analysis of the current traffic conditions, the analysis provided a diverse set of smart transport system options for consideration, prioritizing ITS services for Siem Reap.

The report is structured as follows:

- **Executive Summary:** Summarizes and consolidates the key findings from the analysis and provides the policy and investment recommendations of the report.
- **Chapter 1, Introduction:** Provides the background of the study, and the objective and scope of the study.

- **Chapter 2, Project Description:** presents the overview of the project site, related government plans and regulations, traffic conditions, and an operational plan for the three proposed bus lines.
- **Chapter 3, Electric Bus Technologies:** Analyzes different low-carbon technologies for buses and recommends the most suitable low-carbon technology option for Siem Reap.
- **Chapter 4, Environmental and Financial Assessment:** Examines the environmental, financial, and economic impacts of introducing the recommended e-bus option for the proposed bus lines in Siem Reap.
- **Chapter 5, Smart Transport Systems:** Describes a diverse set of smart transport management technologies and their deployment plan, for further analysis.
- **Chapter 6, Low-carbon Transport Implementation Strategy:** Discusses the operational and financing strategies including a key risk assessment and stakeholder engagement plans.

Chapter 2: Project Description

2.1. Basic Information

Project location

The bus lines proposed by the DUPT are located mostly within the Siem Reap city area and run about 50km through the main roads of the city. The total land area of Siem Reap city is 69,311 m^2. The total length of roads within the city is 662,761m, of which 17,350m is national roads and 114,386m of which is provincial roads.

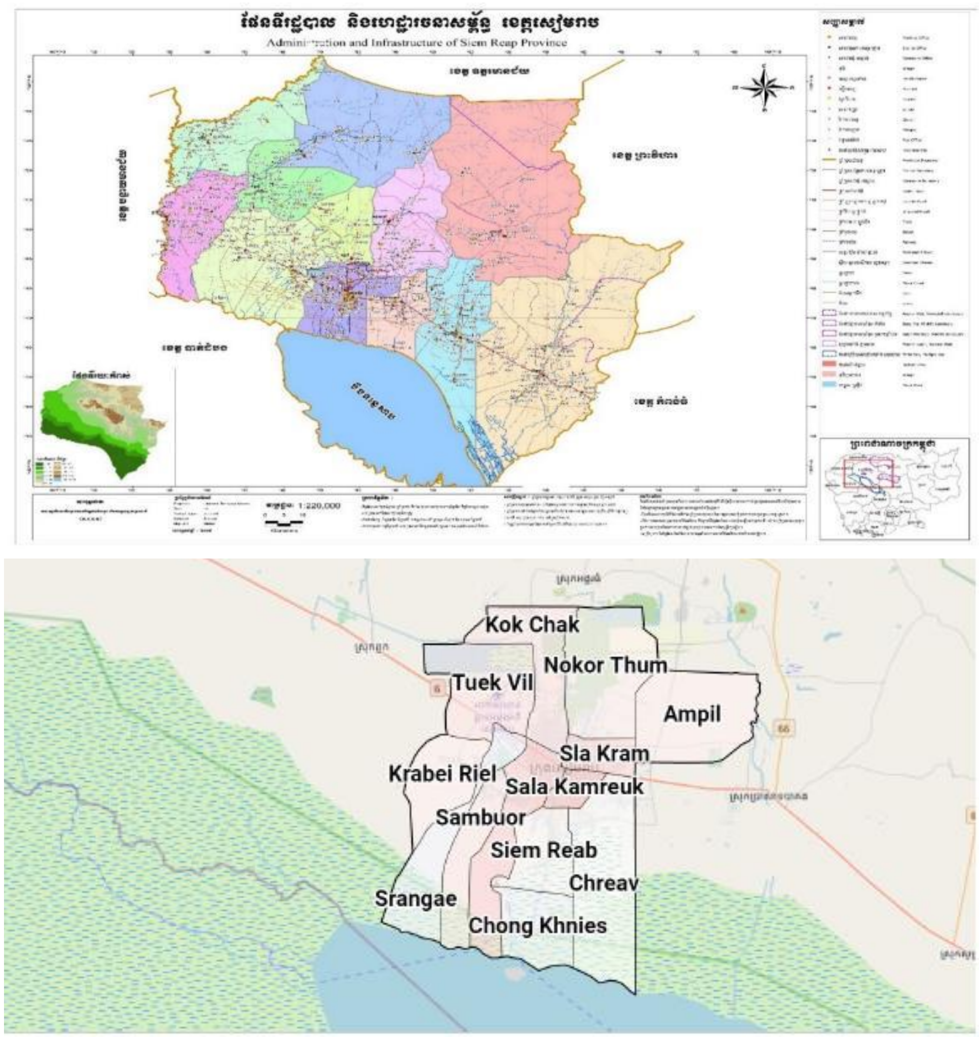


Figure 2: Map of Siem Reap Province and Siem Reap City

Source: Council of Siem Reap Province, 2021 City Population[2]

Table 7: Land Area and Road Length in Siem Reap City

Description	2017	2018	2019
Total Land Area (m^2)		69,311	
Total Road Length	634,840	654,893	662,761
Road length within Siem Reap City	485,314	527,157	531,025
Provincial Road length across Siem Reap City	132,176	110,386	114,386
National Road length across Siem Reap City	17,350	17,350	17,350

Source: Siem Reap Department of Planning, 2020

Population

The population of Siem Reap Province and the City is steadily growing and reached 1.1 million and 0.26 million in 2019, respectively.

Table 8: General Information on the Population in Siem Reap Province

Description	2016	2017	2018	2019
Total Population	1,067,353	1,078,075	1,096,248	1,113,476
Population Growth(%)	3.02	1.00	1.69	1.57
Total Males	527,965	532,130	540,176	549,846
Total Females	539,388	545,945	556,072	563,630
Ratio of Females over Males per 100 persons	102.16	102.60	102.94	102.51
Total Families	220,735	224,995	232,220	238,026
Female-headed household(%)	12.97	13.06	12.87	12.75
Average Family Size (person/family)	4.84	4.79	4.72	4.68
People aged 0-17	434,967	435,240	436,773	438,309
% People aged 0-17	40.75	40.37	39.84	39.36
People aged 18-60	560,285	566,827	576,946	588,306
% People aged 18-60	52.49	52.58	52.63	52.84
People aged 61 and above	72,101	76,008	82,529	86,861
% People aged 61 and above	6.76	7.05	7.53	7.80

Source: Siem Reap Department of Planning, 2020a

Table 9: General Information on the Population in Siem Reap City

Description	2016	2017	2018	2019
Total Population	240,648	243,267	250,798	256,679
Population Growth(%)	7.9	1.1	3.1	2.3

[2] https://www.citypopulation.de/en/cambodia/admin/1710__krong_siem_reap/?mode=gender&map=osm&opacity=0.6&label=name

Total Male	118,104	118,883	122,708	126,761
Total Female	122,544	124,384	128,090	129,918
Ratio of Female over Male in 100 persons	103.8	104.6	104.4	102.5
Total Families	47,225	49,250	51,174	53,574
Female-headed household(%)	13.8	14.2	14.0	14.2
Average Family Size (person/family)	5.1	4.9	4.9	4.8
People aged 0-17	88,226	90,107	92,340	92,517
% People aged 0-17	36.7	37.0	36.8	36.0
People aged 18-60	133,225	134,252	136,696	140,224
% People aged 18-60	55.4	55.2	54.5	54.6
People aged 61 and above	19,197	18,908	21,762	23,938
% People aged 61 and above	8.0	7.8	8.7	9.3

Source: Siem Reap Department of Planning, 2020b

Tourist Visits

Siem Reap is the most popular tourist destination in Cambodia. *Table 10* below shows the number of tourists visiting Siem Reap Province in 2019 and 2020. Tourist visits in 2019 totaled 4.3 million, though declined drastically in 2020 due to the impact of COVID-19 and the global imposition of travel restrictions. The subsequent impact was greater on international tourists than on domestic tourists. In 2019, tourist visits peaked in April, mostly by domestic tourists. International tourists visited Siem Reap steadily throughout 2019 but tended to visit more during the months of November-January, corresponding to the cold winter months in the West and cooler months in Cambodia.

According to the Siem Reap Department of Tourism, major tourist destinations include World Heritage Site Areas (Angkor and other temples in the Angkor Area); areas outside the immediate Angkor Area (Kulen Mountain, Banteay Srey temple, etc.); eco-tourism areas (Tonle Sap, Floating Villages, etc.) The modes of transport used varies between 35-45-seat buses (mostly Chinese and Korean passengers); 15-seat family vans (European passengers); and other rented vehicles.[3]

Table 10: Tourist Visits to Siem Reap Province

Month		2019		2020	
			Total		Total
Jan	Domestic	131,277	402,327	111,586	334,147
	International	271,050		222,561	
Feb	Domestic	273,259	406,190	50,214	169,147
	International	132,931		118,933	
Mar	Domestic	243,591	359,549	2,800	44,969

[3] Collected from the Focus Group Discussions/questions organized by DUPT and GGGI (February 2021)

	International	115,958		42,169	
Apr	Domestic	652,674	838,079	111	765
	International	185,405		654	
May	Domestic	138,658	283,194	850	2,626
	International	144,536		1,776	
Jun	Domestic	119,895	246,497	1,500	3,246
	International	126,602		1,746	
Jul	Domestic	56,962	206,231	1,680	3,470
	International	149,269		1,790	
Aug	Domestic	65,495	223,619	211,500	215,163
	International	158,124		3,663	
Sep	Domestic	117,346	228,023	122,501	125,449
	International	110,677		2,948	
Oct	Domestic	118,292	259,786	169,981	172,225
	International	141,494		2,244	
Nov	Domestic	186,958	380,218	1,425	2,660
	International	193,260		1,235	
Dec	Domestic	220,163	428,593	29,000	30,169
	International	208,430		1,169	
Total	**Domestic**	**2,324,570**	**4,262,306**	**703,148**	**1,104,036**
	International	**1,937,736**		**400,888**	

Source: Provided by Siem Reap Department of Tourism, 2020

Passenger Arrivals/Departures at Siem Reap International Airport

Table 11 below shows the number of passenger arrivals/departures at Siem Reap International Airport. It presents a similar trend to the tourist visit data shown in *Table 10*. The number of passenger arrivals/departures at the airport in 2019 was estimated at around 1.95 million, but in 2020 it decreased to 15% of that level as a result of mass disruption caused by COVID-19 travel restrictions.

Table 11: Passenger Arrivals/Departures at Siem Reap International Airport

	2019						**2020**					
	Departure			Arrival			Departure			Arrival		
	Intl.	Domestic	Total	Intl	Domestic	Total	Intl	Domestic	Total	Intl	Domestic	Total
Jan	211,437	28,095	239,532	200,776	30,896	231,672	158,158	28,292	186,450	143,990	28,082	172,072
Feb	198,512	32,207	230,719	199,108	32,353	231,461	78,758	17,607	96,365	75,899	15,609	91,508
Mar	185,635	29,366	215,001	185,648	26,472	212,120	31,752	7,550	39,302	23,222	6,894	30,116

Apr	141,118	22,265	163,383	144,277	22,333	166,610	-	74	74	-	38	38
May	122,178	20,699	142,877	116,337	20,023	136,360	-	37	37	10	43	53
Jun	103,697	17,677	121,374	104,532	18,038	122,570	-	15	15	2	13	15
Jul	113,533	20,566	134,099	115,103	20,140	135,243	-	19	19	3	11	14
Aug	125,657	21,801	147,458	121,052	20,388	141,440	1	138	139	1	149	150
Sep	94,025	15,520	109,545	88,889	16,655	105,544	-	170	170	-	161	161
Oct	106,961	20,759	127,720	106,520	20,033	126,553	-	72	72	-	129	129
Nov	133,624	25,105	158,729	135,149	24,879	160,028	-	112	112	20	72	92
Dec	145,064	27,371	172,435	149,087	26,418	175,505	5	28	33	-	57	57
Total	**1,681,441**	**281,431**	**1,962,872**	**1,666,478**	**278,628**	**1,945,106**	**268,674**	**54,114**	**322,788**	**243,147**	**51,258**	**294,405**

Source: Provided by Siem Reap International Airport, 2021.

Registered Vehicles

The motorcycle is the predominant mode of transport in both Siem Reap City and the wider Province, representing 90% and 84% of the total number of vehicles respectively, followed by agricultural vehicles and 3-wheeled vehicles. Passenger buses, including mini-buses, represent less than 3% of total traffic in both in the City and Province.

Table 12: Number of Vehicles in Siem Reap Province in 2019

Name of City-District	Motorcycles		Car					Tractor	Agri-cultural Vehicle
	2W	3W	Family car	Passengers		Goods			
				Mini bus	Bus	Pick Up	Truck		
Siem Reap City/District	**57,701 (90%)**	**1,687 (3%)**	**1,403 (2%)**	**1,287 (2%)**	**319 (0.5%)**	**359 (1%)**	**189 (0.3%)**	**27 (0.04%)**	**1,469 (2%)**
Angkor Thom	27,124	32	39	28	7	47	13	102	325
Chi Kreng	24,323	284	284	190	9	222	49	320	7,935
Svay Lea	15,935	9	228	155	13	81	19	176	5,345
Varin	13,875	18	118	89	19	72	29	77	3,748
Angkor Chum	13,975	21	47	15	7	295	27	37	2,995
Srei Snom	15,975	517	19	7	19	59	13	59	3,334
Sot Nikum	14,955	49	275	139	39	57	35	59	2,820
Krolanh	19,573	22	281	221	1	58	23	271	3,322

Bantey Srei	19,123	258	53	51	9	69	72	29	731
Prasat Bakong	23,975	392	1,266	229	-	1,049	103	111	2,802
Puk	24,782	235	602	61	6	121	33	77	2,909
Total	**271,316 (84%)**	**3,524 (1.1%)**	**4,615 (1.4%)**	**2,472 (0.8%)**	**448 (0.1%)**	**2,489 (0.8%)**	**605 (0.2%)**	**1,345 (0.4%)**	**37,735 (12%)**

Source: Siem Reap Department of Public Works and Transport, 2020

2.2 Study Area Profile

The three bus lines proposed by the DUPT run for about 50km using the main roads of Siem Reap City. Line 1 runs from Svay Thom Market to Siem Reap International Airport. Line 2 starts and finishes at the Administration Office of Siem Reap, while Line 3 runs from Chong Kneas Port to the Pedagogical and Vocational School.

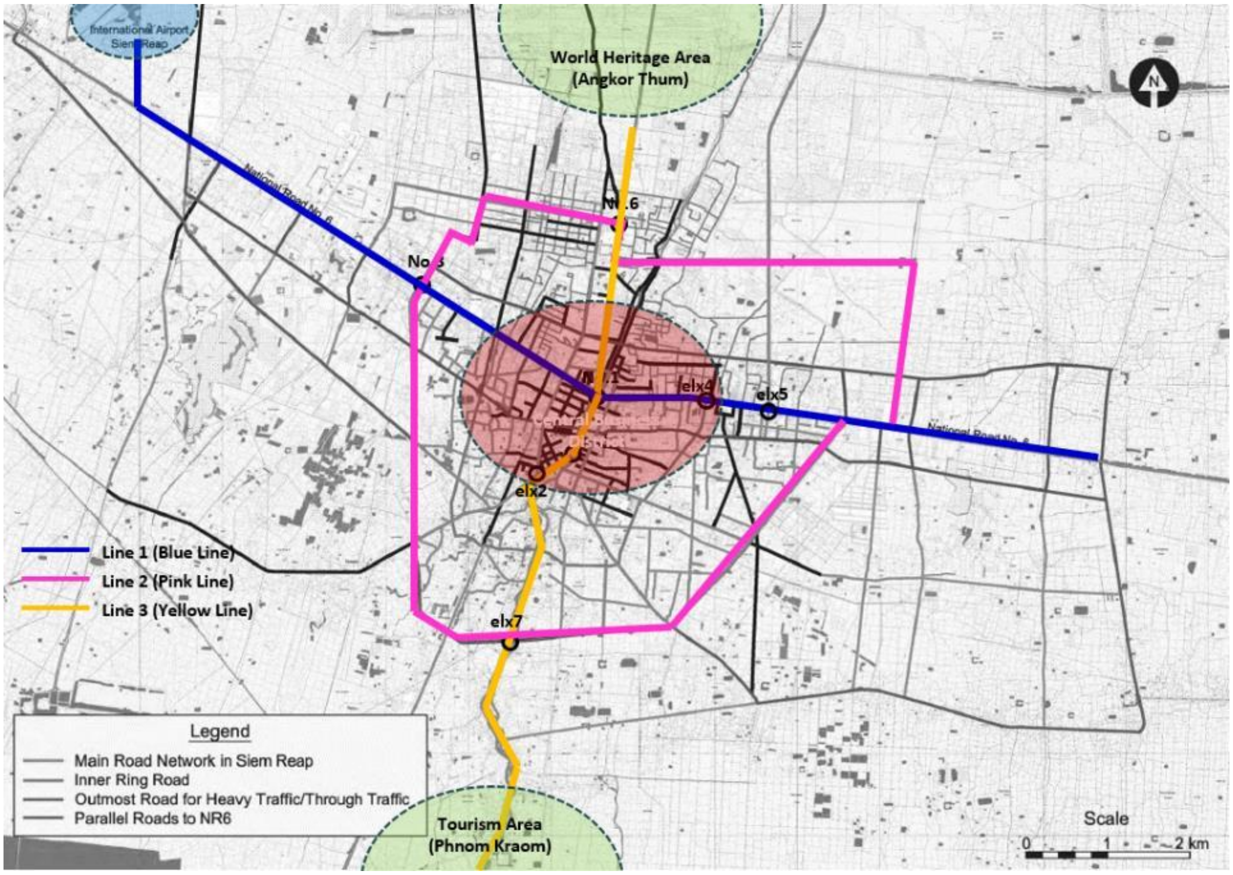


Figure 3: Map of Proposed 3 Bus Lines in Siem Reap

According to the Siem Reap Municipality city center improvement plan, there are seven categories of areas including the CBD, the CBD fringe, the adjacent area of the city center within the ring road, the urban corridor, the suburban area beyond the ring road, the APSARA cultural and tourist zone, and the headquarters of the provincial government. In order to connect these seven critical areas in a sustainable manner, the government has suggested the above-illustrated three lines as the priority routes for the potential introduction of electric buses.

Line 1 (Blue) is National Road No. 6 connecting Siem Reap International Airport to the city center area, playing an important role in meeting tourist demand. Line 2 (Pink) is a circular line running adjacent to the city center, the CBD fringe and the APSARA cultural/tourism zone. The line is also assigned as a Siem Reap Bypass Road, leading heavy vehicles to the bypass road instead of entering Siem Reap City via National Road No. 6. Line 3 (Yellow) will be utilized as a service road linking the CBD and the World Heritage Areas including Angkor Thum and Phnom Kraom, in the process thus creating an urban structure comprising the town center of the World Heritage Area town and a tourist destination in its own right.

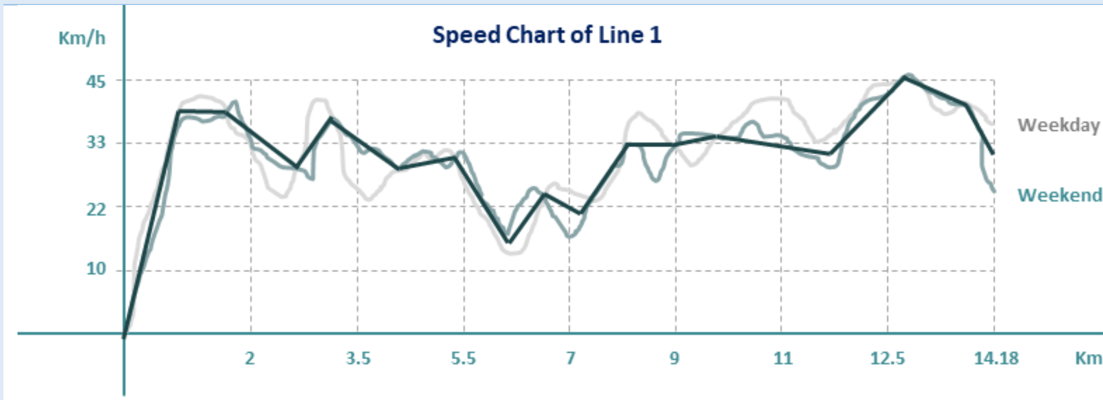
The below provides a detailed overview of each of the proposed three bus lines:

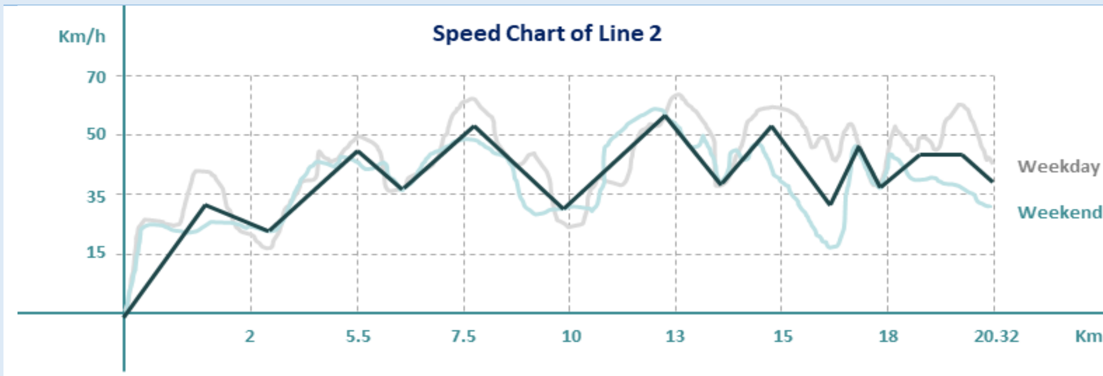
- **Line 1 (Blue):**
  - Distance: 13.66km.
  - Maximum speed: 46km/h on weekdays and 45km/h on weekends.
  - Average speed: 29km/h on weekdays and weekends.
  - Movement duration on weekdays: 26.52 mins (AM) and 30.05 mins (PM).
  - Movement duration on weekends: 29.39 mins (AM) and 29.08 mins (PM).
  - Slope level: Maximum and minimum of 0°.

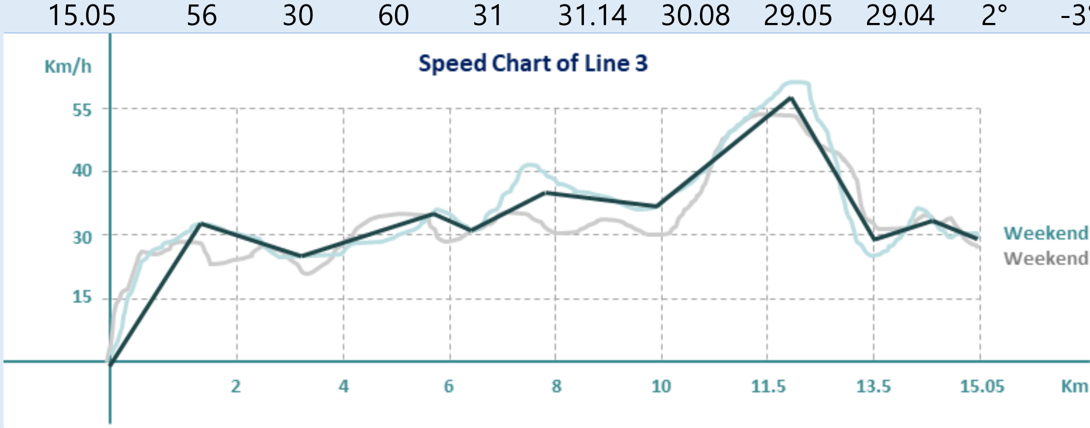
- **Line 2 (Pink):**
  - Distance: 20.32 km.
  - Maximum speed: 69 km/h on weekdays and 61 km/h on weekends.
  - Average speed: 33 km/h on weekdays and 30 km/h on weekends.
  - Movement duration on weekdays: 44.54 mins (AM) and 33.13 mins (PM).
  - Movement duration on weekends: 39.43 mins (AM) and 42.44 mins (PM).
  - Slope level: Maximum of 2° and minimum of -2°.

- **Line 3 (Yellow):**
  - Distance: 15.05km.
  - Maximum speed: 56 km/h on weekdays and 60 km/h on weekends.
  - Average speed: 30 km/h on weekdays and 31 km/h on weekends.
  - Movement duration on weekdays: 31.14 mins (AM) and 30.08 mins (PM).
  - Movement duration on weekends: 29.05 mins (AM) and 29.04 mins (PM).
  - Slope level: Maximum of 2° and minimum of -3°.

Table 13: Traffic Information of the Proposed 3 Lines

<table>
<tr><th rowspan="3">Line</th><th rowspan="3">Distance (km)</th><th colspan="4">Speed (km/h)</th><th colspan="4">Movement Duration (mins)</th><th colspan="2" rowspan="2">Slope (degree)</th></tr>
<tr><th colspan="2">Weekday</th><th colspan="2">Weekend</th><th colspan="2">Weekday</th><th colspan="2">Weekend</th></tr>
<tr><th>Max</th><th>Mean</th><th>Max</th><th>Mean</th><th>AM</th><th>PM</th><th>AM</th><th>PM</th><th>Max</th><th>Min</th></tr>
<tr><td rowspan="2">Line1 (Blue)</td><td>13.66</td><td>46</td><td>29</td><td>45</td><td>29</td><td>26.52</td><td>30.05</td><td>29.39</td><td>29.08</td><td>0°</td><td>-0°</td></tr>
<tr><td colspan="11">

Running along a segment of NR6, starts from the intersection between NR6 & Road # 67, crossing Makro Supermarket, Chhong Kaosu, Psar Leu, Jayavarman II roundabout, Preh Ang Chek Preh Angjom then heading to the airport and return.</td></tr>
<tr><td rowspan="2">Line2 (Pink)</td><td>20.32</td><td>69</td><td>33</td><td>61</td><td>30</td><td>44.54</td><td>33.13</td><td>39.43</td><td>42.44</td><td>2°</td><td>-2°</td></tr>
<tr><td colspan="11">

Starting from Siem Reap Administration Office, heading to other areas and returning to the Administration Office.</td></tr>
<tr><td rowspan="2">Line3 (Yellow)</td><td>15.05</td><td>56</td><td>30</td><td>60</td><td>31</td><td>31.14</td><td>30.08</td><td>29.05</td><td>29.04</td><td>2°</td><td>-3°</td></tr>
<tr><td colspan="11">

Starting from Chhong Kneas port, Sangkar Chhong Kneas, Psar Krom crossroads, and a few other areas, Kuntea Bopha Hospital, Vocation School and return.</td></tr>
</table>

2.3 Transportation Status

2.3.1 Traffic Volume in the Study Area

In February 2021, the GGGI Cambodia team conducted a traffic count survey under the supervision of the GGGI transport lead. The survey was carried out on 5-6 February 2021 at the seven Survey Stations as shown in Figure 4, by 28 enumerators and five team leaders from the MPWT and the Department of Public Works and Transport of Siem Reap Province. The results showed that Siem Reap's traffic volume during the survey period was significantly below the level of the previous year due to very limited tourist visits during the COVID-19 pandemic and construction work on National Road No. 38. Therefore, it is recommended that the results of the survey are considered as an absolute minimum scenario. The traffic volume survey at each survey station was conducted by:

a. Performing the survey on seven intersections.
b. Counting traffic volume by direction at intersections. (Left-turn, right-turn, and straight volume by direction (east-bound, west-bound, south-bound, and north-bound).
c. Carrying out two surveys; one on a weekday and one on a weekend.
d. Conducting the survey for 6 hours per day; at peak times (07:00~09:00, 16:30~18:30) and non-peak times (12:00~14:00)
e. Classifying vehicles into five types including passenger car, bus, truck, motorcycle, and others.
f. Recording the videos at the intersections and then analyzing the videos.

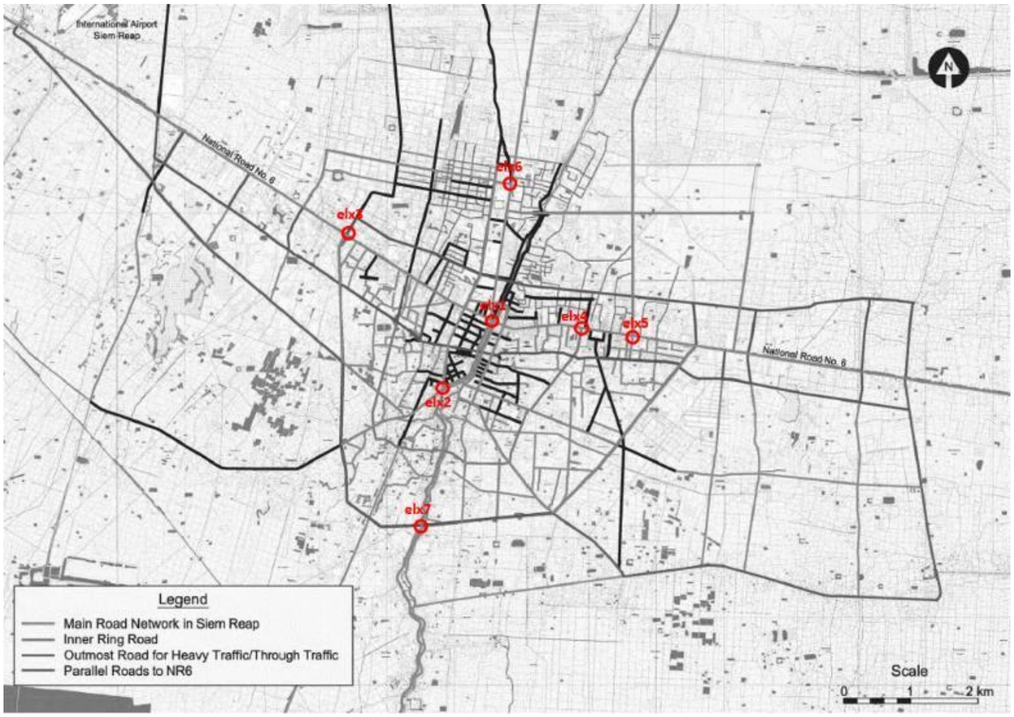


Figure 4: Location Map of Survey Station of 2021

Methodology

Since the traffic volume survey was conducted at intersections, it is necessary to convert the intersection traffic volume into the link traffic volume. To calculate this, the following method is used. In *Figure 5* below the traffic volume in the east-west direction at the intersection can be calculated as the average of the traffic volume in Section A and Section B. In terms of the traffic volume in Section A, it is the sum of traffic volume going from east to west and traffic volume going from west to east. This equation is as follows:

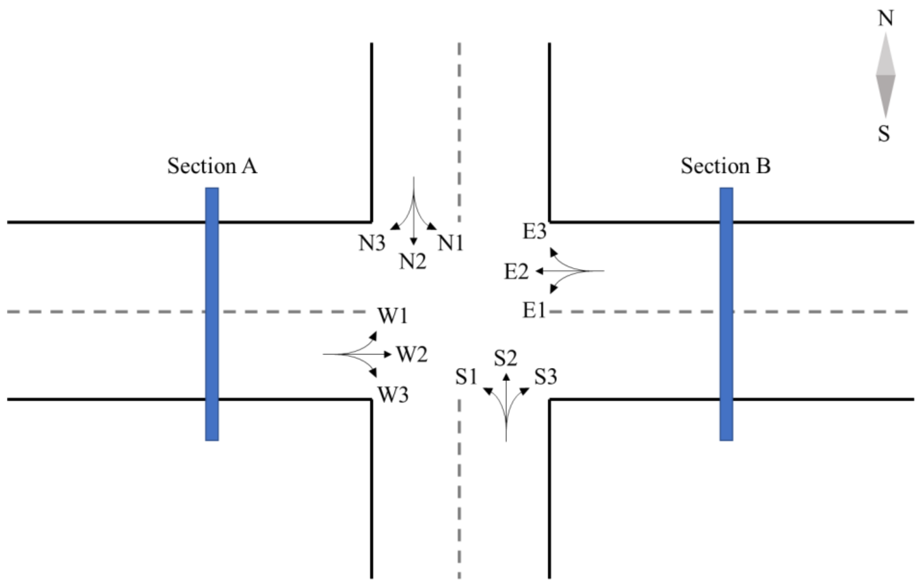


Figure 5: Directional Volume at intersection

$$Volume\ A(west\ to\ east) = W1 + W2 + W3$$

$$Volume\ A(east\ to\ west) = N3 + E2 + S1$$

$$\therefore\ Volume\ A = Volume\ A(west\ to\ east) + Volume\ A(east\ to\ west)$$

$$= W1 + W2 + W3 + N3 + E2 + S1$$

The traffic volume in Section B and on the east-west axis (Volume EW) can be calculated as follows:

For the north-south axis, it is calculated in the identical way as for the east-west axis.

$$Volume\ B = E1 + E2 + E3 + N1 + W2 + S3$$

$$Volume\ EW = \frac{(Volume\ A) + (Volume\ B)}{2}$$

$$= \frac{E1 + 2E2 + E3 + W1 + 2W2 + W3 + N1 + N3 + S1 + S3}{2}$$

Line 1 (Blue Line) – Connecting the City Center and Siem Reap International Airport

The blue-colored line (Line 1), which is about 13.66km long, is a route that is responsible for traffic on the east-west axis of Siem Reap. Line 1 runs along a segment of National Road No. 6, starting from the intersection of National Road No. 6 and Road No. 67, crossing Makro Supermarket, Chhong Kaosu, Psar Leu, Jayavarman II roundabout, Preh Ang Chek Preh Angjom and then heading to Siem Reap International Airport. Line 2 connects the city center and Siem Reap International Airport and plays an important role in absorbing increased future tourist arrivals.

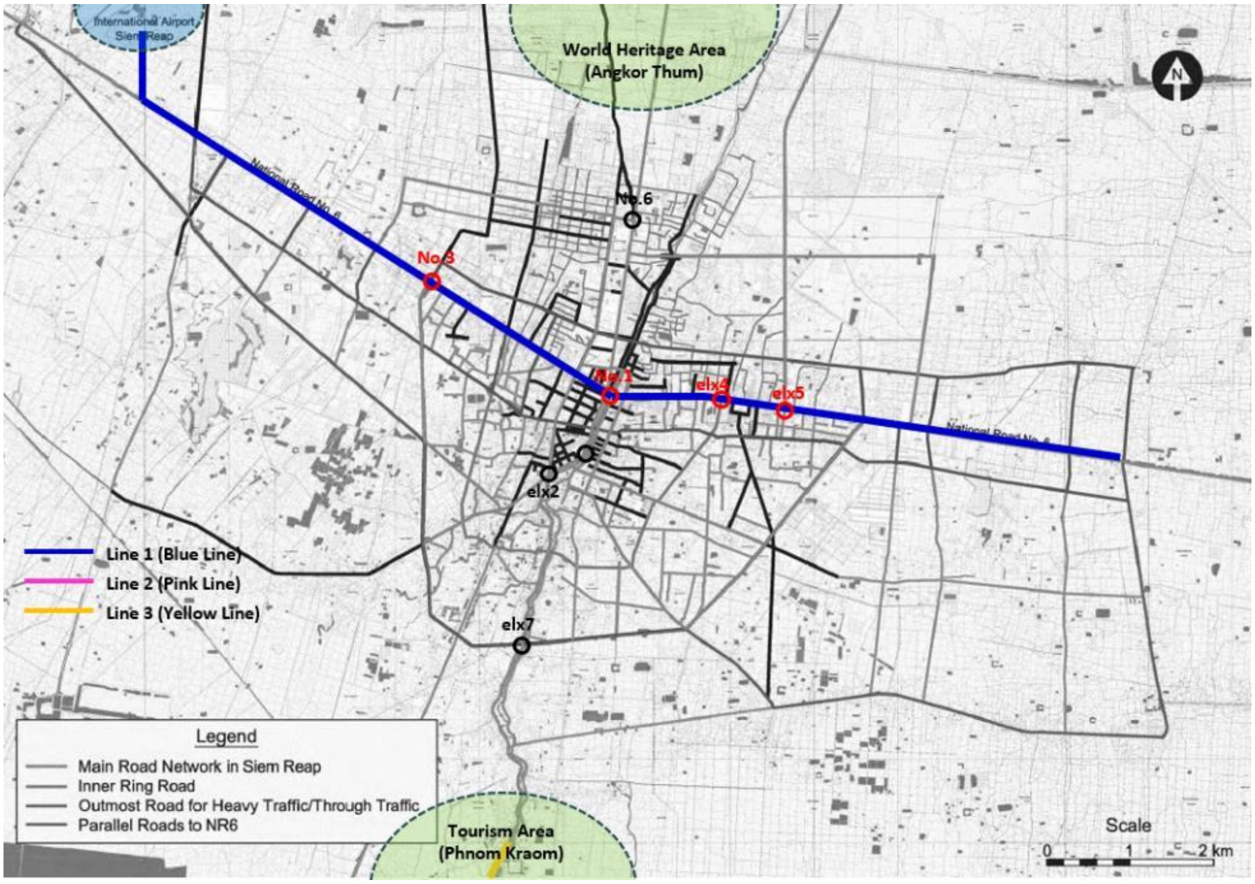


Figure 6: Traffic Volume Survey - Line 1

In terms of modal share on Line 1 on weekdays, motorcycles play an important role, accounting for about 73.2% of total traffic, while passenger cars account for 23.1% (10,943). The share of heavy vehicles, including buses and trucks, accounts for just 3.7%., while bus usage itself is very low at 1.7% of total modal share.

Table 14: Traffic Volume Survey - Line 1

Vehicle Type	Time	Weekday				Weekend			
		3	1	4	5	3	1	4	5
Passenger Car	AM Peak	577	865	1167	647	316	720	1270	539
	Nonpeak	658	835	1152	814	443	890	1038	874
	PM Peak	786	1061	1428	954	482	918	1461	1003
Bus/Truck	AM Peak	155	67	240	139	100	93	135	231
	Nonpeak	193	101	187	175	95	100	164	195
	PM Peak	128	66	164	143	124	72	127	140
Motorcycle	AM Peak	1,839	2,108	4,380	2,836	1,669	2,702	3,082	3,200

	Nonpeak	1,525	2,732	2,844	2,454	1,070	2,554	3,412	1,959
	PM Peak	2,886	2,809	4,421	3,774	1,303	2,147	3,973	3,971
Total (veh)	AM Peak	2,571	3,040	5,787	3,622	2,085	3,515	4,487	3,970
	Nonpeak	2,376	3,668	4,183	3,443	1,608	3,544	4,614	3,028
	PM Peak	3,800	3,936	6,013	4,871	1,909	3,137	5,561	5,114
Total (PCU)	AM Peak	1,806	2,053	3,837	2,343	1,351	2,257	3,081	2,601
	Nonpeak	1,807	2,403	2,948	2,391	1,168	2,367	3,072	2,244
	PM Peak	2,485	2,598	3,966	3,127	1,381	2,135	3,701	3,268

The traffic volume (Passenger Car Unit) on Line 1 on weekdays ranged from 1,500 to 4,000 and was found to be the busiest among the analyzed routes. Unlike Line 2, the Line 1 traffic volume on weekends was slightly lower than that on weekdays, because commuting is the main purpose of traffic for a significant number of users.

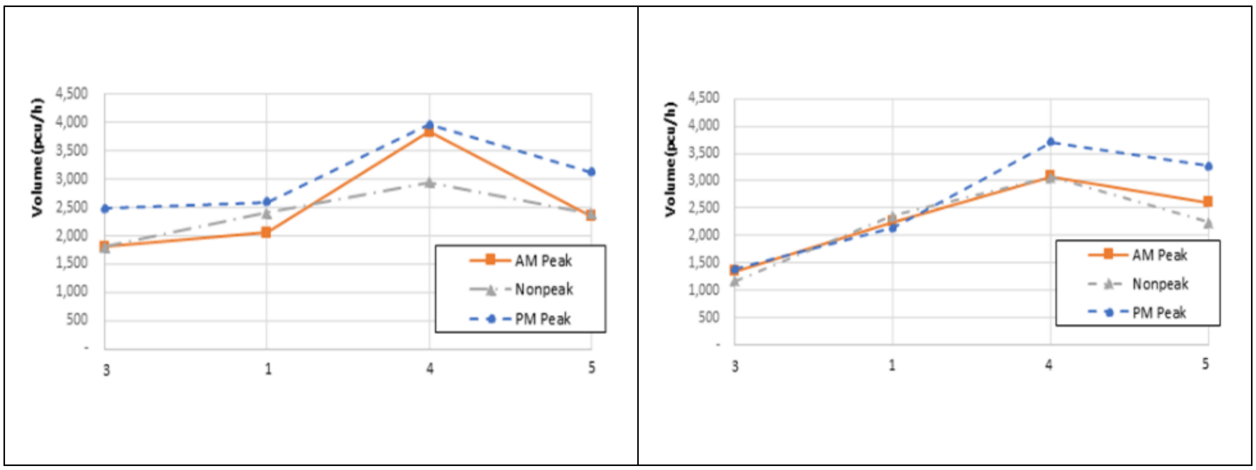


Figure 7: Weekday and Weekend Volume (Passenger Car Unit) - Line 1

Line 2 (Pink Line) – Circular Line Around City Center Outskirts

The pink-colored line (Line 2), which is about 20.32km long, is a circular route following the outskirts of the city center. Line 2 start from the Siem Reap Administration Office, heading around surrounding areas and returning to the Siem Reap Administration Office. As one of the core service lines, Line 2 will be utilized by tourists and local people to enjoy connectivity of urban services and tourism attractions.

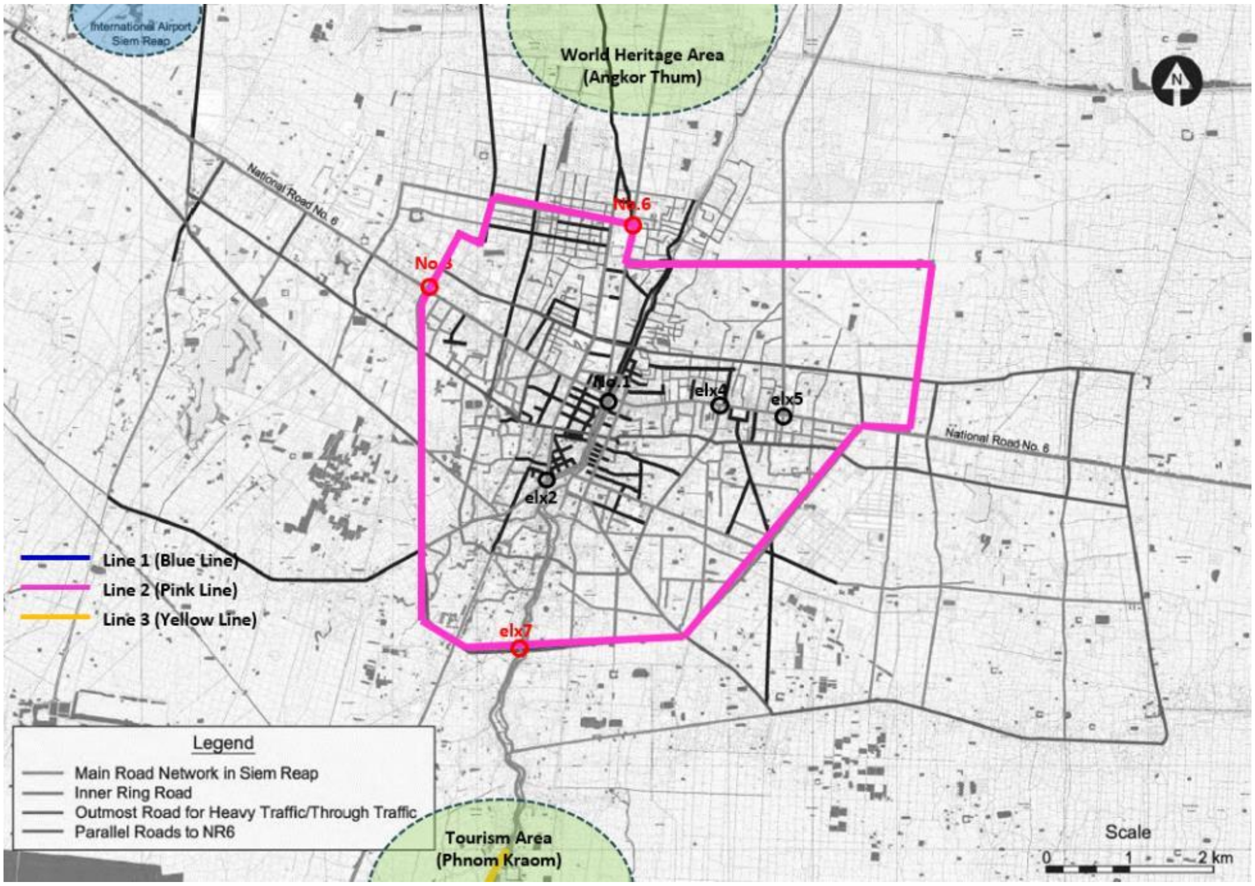


Figure 8: Traffic Volume Survey - Line 2

In terms of modal share on Line 2 on weekdays, motorcycles are clearly the dominant mode of transportation, accounting for approximately 69.5% of total traffic. Next is passenger cars, accounting for 16.9% (1,017). Heavy vehicles, including buses and trucks, account for 13.6%, with trips by bus comprising a minimal 1.3%.

Table 15: Traffic Volume Survey – Line 2

Vehicle Type	Time	Weekday				Weekend			
		6	3	7	-	6	3	7	-
Passenger Car	AM Peak	141	131	91	-	99	339	57	-
	Nonpeak	86	127	77	-	86	463	65	-
	PM Peak	120	158	87	-	121	460	78	-
Bus/Truck	AM Peak	43	82	174	-	28	81	183	-
	Nonpeak	42	65	153	-	20	65	165	-
	PM Peak	30	56	173	-	28	61	155	-
Motorcycle	AM Peak	487	551	212	-	778	1,126	254	-
	Nonpeak	597	432	198	-	506	1,172	184	-
	PM Peak	809	606	288	-	842	2,228	259	-
Total (veh)	AM Peak	671	763	476	-	904	1,546	495	-
	Nonpeak	725	624	428	-	611	1,700	413	-
	PM Peak	958	819	548	-	991	2,749	491	-
Total (PCU)	AM Peak	471	571	545	-	544	1,064	550	-
	Nonpeak	469	473	482	-	379	1,179	487	-
	PM Peak	585	573	577	-	598	1,696	518	-

The traffic volume (Passenger Car Unit) on Line 2 on weekdays is usually around 1,000 vehicles, which is relatively low compared to other Siem Reap traffic survey points. However, there are over 1,000 units of traffic on weekends. This is believed to be because tourism demand accounts for a significant number of the travel purposes of users using Line 2. In particular, the traffic volume on the weekend of Spot 1 see significant growth, showing more than twice the traffic volume on weekdays.

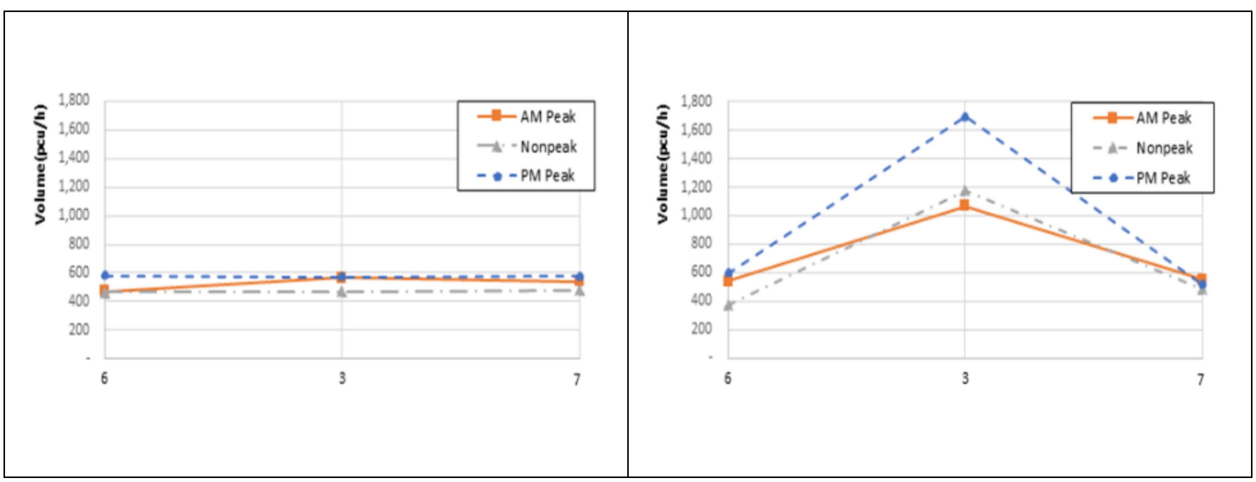


Figure 9: Weekday and Weekend Volume (Passenger Car Unit) - Line 2

Line 3 (Yellow Line) – Connecting the City Center and Tourist Destinations

The yellow-colored line (Line 3), which is about 15.05km long, is the route responsible for carrying north-south axis traffic in Siem Reap. Line 3 starts from Chhong Kneas port and continues to Sangkar Chhong Kneas, Psar Krom crossroads, Kantha Bopha Hospital, and the Vocation School before returning. Line 3 connects the fundamental tourist destinations of the Angkor World Heritage Site with other urban tourist facilities and plays a pivotal role in formulating the urban structure as a service town of the World Heritage Site and as a tourist destination.

Figure 10: Traffic Volume Survey - Line 3

In terms of modal share on Line 3, motorcycles represent the majority vehicular use, accounting for 75.3% (15,975). Passenger car usage comes second at is 3,512 on Line 3. The number of trips by bus accounts for 3.8% (800). Meanwhile, truck volume is relatively small at 4.3% (917).

Table 16: Traffic Volume Survey - Line 3

Vehicle type	Time	Weekday				Weekend			
		6	1	3	7	6	1	2	7
	AM Peak	403	232	304	180	322	227	219	138

Passenger Car	Nonpeak	239	227	275	148	449	256	253	151
	PM Peak	659	337	322	187	1,283	301	364	186
Bus/Truck	AM Peak	462	39	36	28	149	31	54	22
	Nonpeak	280	42	41	16	65	43	59	25
	PM Peak	697	22	32	27	43	30	50	26
Motorcycle	AM Peak	937	626	1,007	1,625	1,453	854	1,144	1,597
	Nonpeak	1,129	891	1,371	1,344	1,250	795	1,446	1,301
	PM Peak	2,407	1011	1,668	1,959	2,674	768	1,918	1,637
Total (veh)	AM Peak	1,794	621	878	1,047	1,924	1,113	1,416	1,756
	Nonpeak	1,364	755	1,042	853	1,763	1,093	1,757	1,476
	PM Peak	3,255	885	1,219	1,219	4,000	1,099	2,332	1,849
Total (PCU)	AM Peak	1,796	623	880	1,049	1,347	716	899	981
	Nonpeak	1,364	757	1,043	852	1,204	740	1,094	852
	PM Peak	3,257	887	1,220	1,221	2,706	745	1,423	1,057

The variation in traffic volume between points was larger than that of Line 1 and Line 2. In particular, the traffic volume at Point 6 was higher than that at other points on the route, largely due to higher demand given the proximity of Point 6 to Angkor Wat.

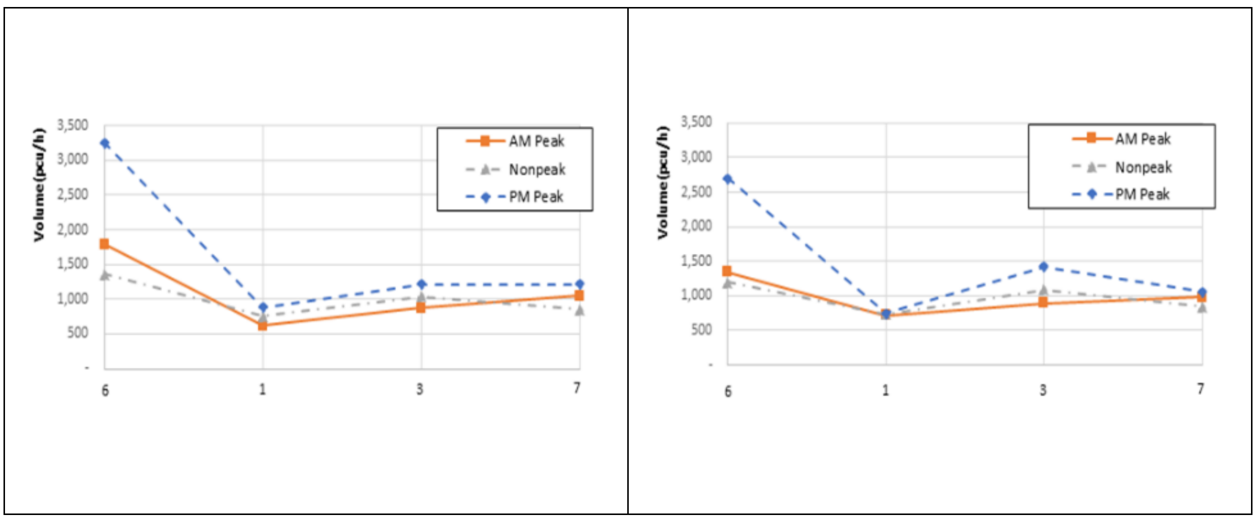


Figure 11: Weekday and Weekend Volume (Passenger Car Units) - Line 3

As a result of the traffic volume survey, the total number of vehicles observed at the survey points was 331,010. Of these, motorcycles accounted for 76.4% (245,338) of all vehicles, followed by cars (21.7%), trucks (3.1%), and buses (1.9%). Based on the survey results, more than 95% of Siem Reap citizens prefer to use private transportation, which leads to severe traffic congestion and high carbon emissions. Therefore, it is recommended to improve common transport services to resolve congestion issues and reduce carbon emissions in Siem Reap.

The introduction of e-buses and a smart bus management system (BIS and BMS) can convert demand for private into common transportation by improving the satisfaction of transportation users. Due to the roundabouts on the high-volume Line 2, managing traffic flow is a challenge, hence the recommendation to introduce a traffic signal control system and ATMS to improve traffic flow efficiency.

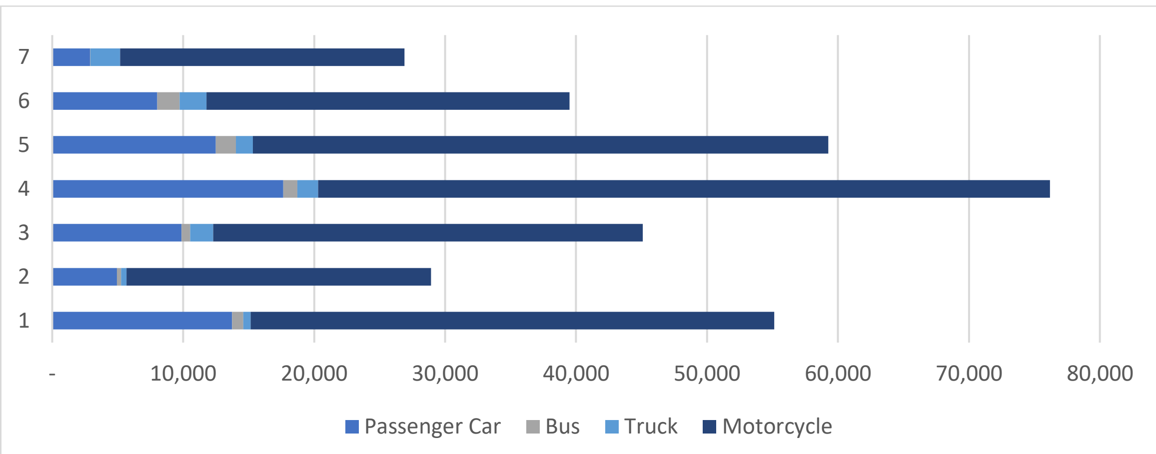


Figure 12: Traffic Volume by Mode

Table 17: Traffic Volume by Mode

Spot	Passenger Car		Bus		Truck		Motorcycle	
	Volume	Ratio	Volume	Ratio	Volume	Ratio	Volume	Ratio
1	13,735	25.2%	845	1.5%	558	1.0%	39,995	73.3%
2	4,941	17.3%	324	1.1%	402	1.4%	23,269	81.5%
3	9,878	22.8%	663	1.5%	1,741	4.0%	32,811	75.7%
4	17,637	23.6%	1,088	1.5%	1,583	2.1%	55,884	74.9%
5	12,486	21.5%	1,545	2.7%	1,293	2.2%	43,931	75.8%
6	8,012	21.4%	1,709	4.6%	2,057	5.5%	27,735	74.0%
7	2,889	11.7%	35	0.1%	2,251	9.1%	21,713	88.1%
Total	69,578	21.7%	6,209	1.9%	9,885	3.1%	245,338	76.4%

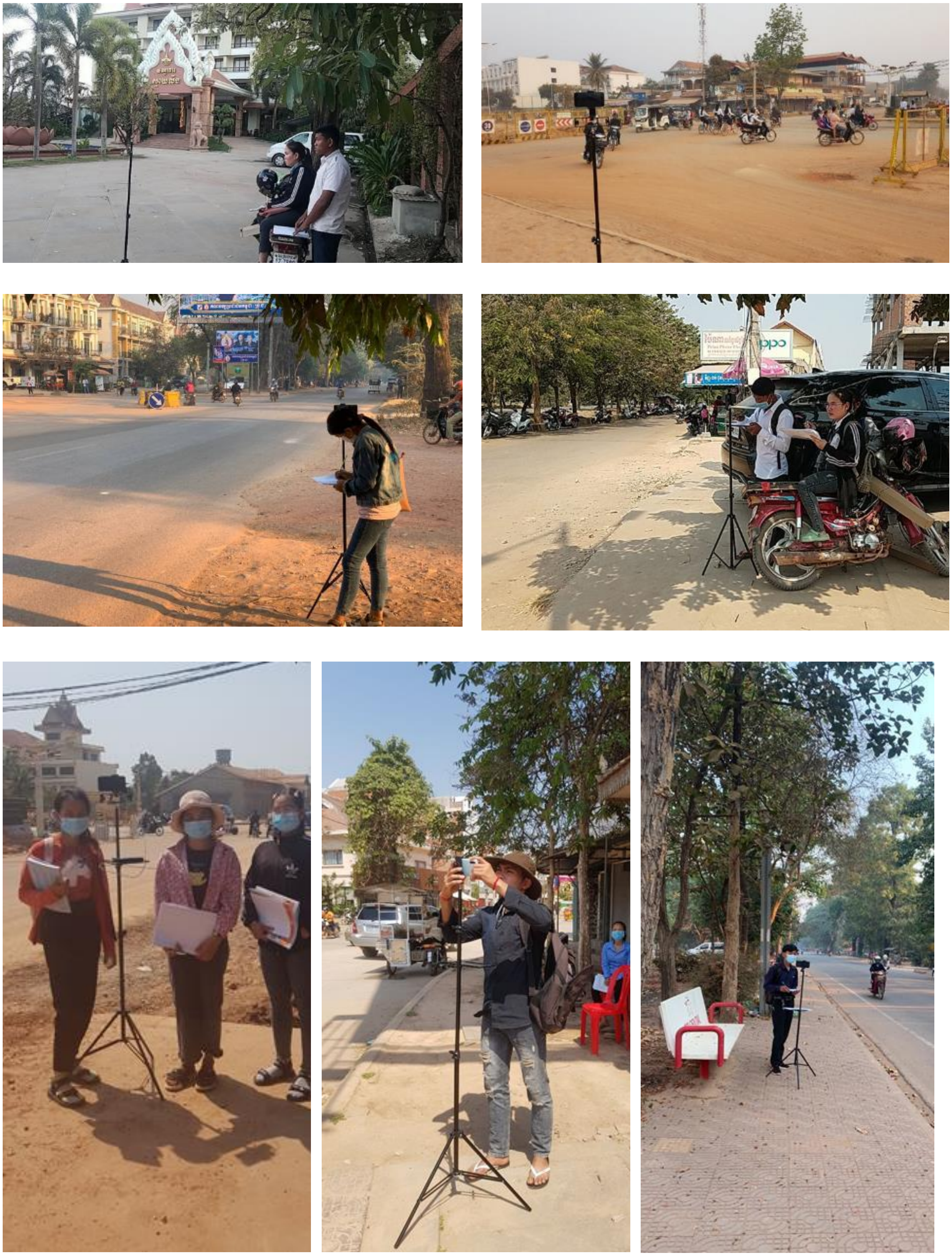


Figure 13: Traffic Volume Survey Photos

2.3.2 Transport Satisfaction in the Study Area

In February 2021, the GGGI Cambodia team conducted a transport satisfaction survey under supervision of the GGGI transport lead. The survey was carried out on February 4 2021 in the city center as shown in *Figure 14* to understand satisfaction levels with transport services. The transport satisfaction survey was conducted via:

a. A user satisfaction survey on transportation in Siem Reap City.
b. Surveying 240 people, taking around 10-20 minutes per person.
c. Conducting the survey with a diverse set of age groups and in different regions where possible.
d. Translating the survey sheet into Khmer language for use by citizens and government officers.

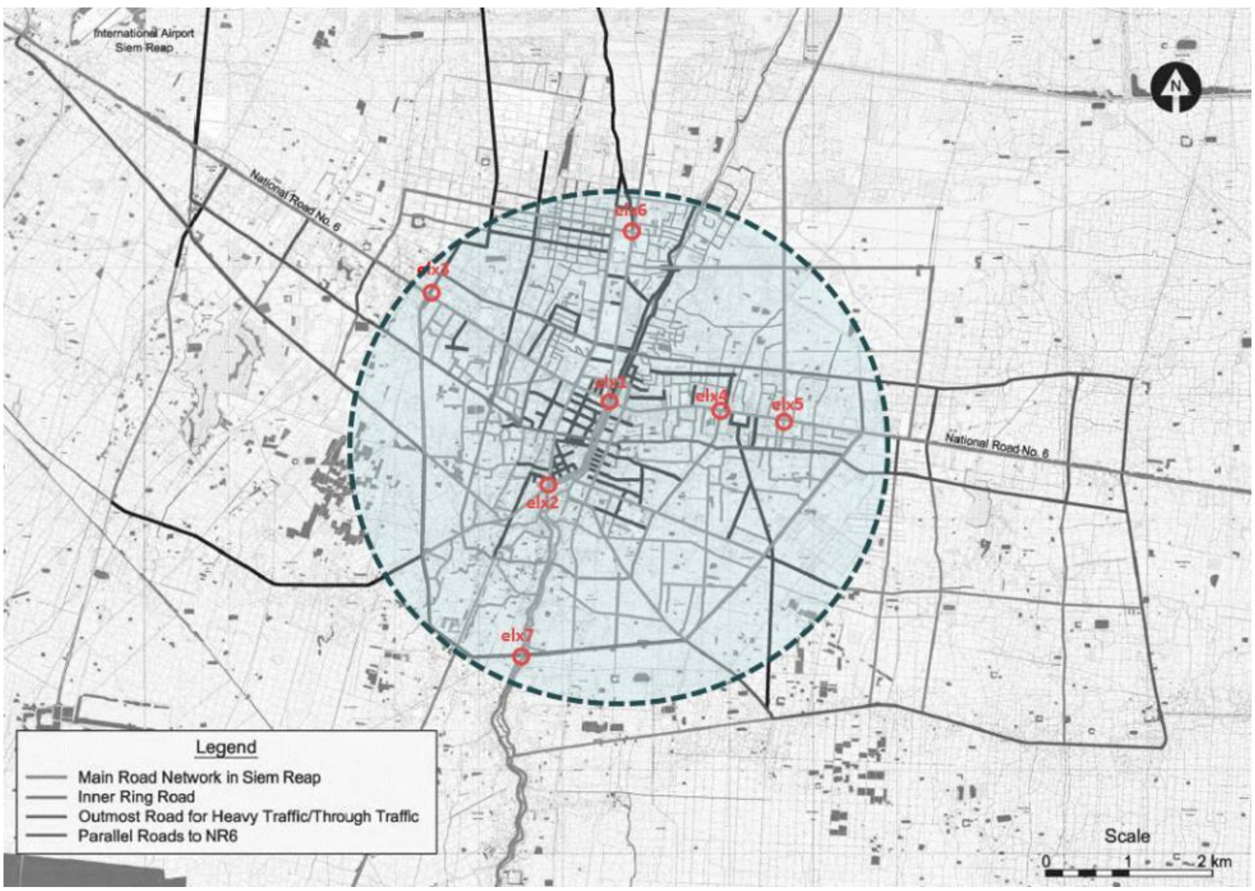


Figure 14: Location Map of Satisfaction Survey Areas of 2021

The transport satisfaction survey questioned 240 people. Among them, 62.9% were male and 37.1% were female, with an age range from teenagers to adults aged 60+. Of the respondents, 81.3% lived in Siem Reap, and 18.8% lived in a region other than Siem Reap. Survey respondents were employed in sales/service occupations (about 22.1%), followed by students, followed by production/transport/general labor. Of the respondents, 9.2% owned a car, and 90.8% owned a motorcycle. As the proportion of motorcycle owners is very high, motorcycles represented 71.7% of the main means of transportation, followed by tuk-tuks (12.1%) and taxis (11.3%).

As for Siem Reap's main means of transportation not owned by the individual travelling in the vehicle, buses accounted for 16.7%, inter-regional buses 7.4%, and taxis 18.5%, and while than half, or 57.4%, use tuk-tuks (tricycle). Regarding transportation service satisfaction among survey respondents, only 1.3% answered 'very satisfied', 35.4% answered 'satisfied', and 43.8% answered 'average'.

As part of the survey, respondents ranked their issues with transportation services from first to fifth. To calculate the overall consolidated score of the issues, five points were given for first place, four points for second place, three points for third place, two points for fourth place, and one point for fifth place. The survey results showed that the greatest three perceived problems in the transportation sector among citizens of Siem Reap was frequent congestion at intersections (658 points) followed by frequent congestion on roadways (490 points), then lack of parking spaces and facilities (396 points). In fourth place came non-recurrent congestion due to accidents or road construction (266 points), with lack of traffic information or inaccuracy of the information (173 points) coming fifth.

Table 18: Transportation Issues in Siem Reap, Cambodia

Transportation Issues	1st	2nd	3rd	4th	5th	Score	Rank
Frequent congestion at intersections	110	19	6	3	8	658	1
Frequent congestion on roadways	62	36	8	3	6	490	2
Lack of parking spaces and facilities	9	39	39	31	16	396	3
Non-recurrent congestion due to accidents or road construction	11	35	15	9	8	266	4
Lack of traffic information or inaccuracy of the information	5	24	12	5	6	173	5

The transportation survey was also analyzed using the same procedure as the transportation satisfaction survey. Those who did not use common transportation were excluded from respondent results of the transportation satisfaction survey. The survey outcome showed that Siem Reap citizens considered lack of information on common transportation as the most significant issue (111 points), followed by the increase in transfer and travel time due to insufficient bus routes (94 points), limited and irregular bus frequency (91 points), inaccurate transportation information (88 points), and finally inaccurate transportation information (82 points).

Table 19: Common Transportation Issues in Siem Reap

Transportation Issues	1st	2nd	3rd	4th	5th	Score	Rank
Lack of information on transportation	14	5	4	3	3	111	1
Increase in transfer and travel time due to insufficient bus routes	10	4	8	1	2	94	2
Limited and irregular bus frequency	5	10	5	4	3	91	3
Inaccurate transportation information	6	10	2	4	4	88	4
Poor facilities of bus vehicles and lack of services	5	4	9	6	2	82	5

According to the results of the transport satisfaction survey, three types of transport-related issues including poor traffic management, insufficient bus services, and illegal parking were identified as primary factors.

To address the identified traffic management issues, including non-recurrent and frequent congestion at intersections and roadways, and the lack of traffic information such as congestion information, construction information and accident information, it is suggested to consider implementing smart traffic management systems. It is possible to optimize traffic management of arterial roads and maximize the utilization rate of roads within cities through traffic system management, intersection monitoring and incident management through connection with relevant agencies. To commensurately improve the level of satisfaction with the traffic environment, it is recommended to consider smart traffic management systems as follows:

- **Traffic Demand Management System**: Alleviating traffic congestion and controlling traffic demand by forcibly limiting specific, selected groups of vehicles using tools such as alternate no-driving systems and car sharing.
- **Advanced Traffic Management System (ATMS)**: Providing users with traffic information in real time, supporting managers to perform traffic management duties, and establishing necessary policies by collecting and providing traffic data on urban arterial roads.
- **Traffic Signal Control System**: Controlling traffic flow at signalized intersections by providing traffic lights (i.e., red, yellow, and green), which respond to traffic demand as collected in real-time by traffic detection systems such as surface magnetic loops and gantry-based image sensors.

To attract more common transport users, enhanced bus services could be introduced to address the identified issues of lack of information on transportation, long transfer and travel time, and inaccurate transportation services. Through introducing advanced bus management services, it would be possible to coordinate plans based on the bus operation status (bus locations and estimated delays) collected in real-time for safe and efficient bus operations, providing various bus-related information (such as preset bus timetables), real-time bus operational status, and the expected bus arrival time at bus stops. Therefore, it is recommended to undertake a further feasibility analysis on public bus management services, a cost/benefit analysis of each system and identifying priority projects which would be most beneficial to the city as below:

- **Bus Management System (BMS)**: Managing bus information by collecting, integrating, and disseminating the bus information, and enhancing punctuality and safety of bus operations based on effective bus routes and operations management in real-time.
- **Bus Information System (BIS)**: Providing real-time bus information to users and transferring information through BIS panels at bus stops, mobile phones, and the internet.
- **Bus Priority Management System**: Generating and sending bus priority requests to traffic-light controllers at either the local or central levels via a centrally controlled private Wi-Fi communication network.
- **Electric Low-Floor Bus**: Replacing diesel-powered buses with electric-powered vehicles which emit less carbon-based exhaust fumes, operate noiselessly, and provide ease of access for persons with disabilities, children, and seniors via low-floor access.

The identified lack of parking spaces and facilities can be addressed by initiating a parking management system to enhance safety and efficiency on the road. From the satisfaction survey, parking is a source of constant frustration in Siem Reap. Illegal roadside parking disrupts travel and has potential to cause traffic accidents. Improved parking management measures can be implemented as below: It is suggested to consider improved parking management measures as follows:

- **Illegal Parking Enforcement System (IPES)**: Efficiently identify violators, allowing for targeted enforcement so parking control officers can identify and tackle disruptions proactively prior to them becoming a threat to traffic safety and flow.
- **Electronic Parking Payment System**: Installing systems at public parking lots experiencing higher demand, allowing drivers to pay parking fares electronically (e.g., smart card) to reduce delays at payment stations and ultimately promote the utility of parking facilities by increasing user convenience.

Figure 15: Transport Satisfaction Survey Photos

2.4 Relevant Green Development Plans and Policies

Overarching national plans and policies that support clean and low carbon transport development in Cambodia include the following:

2.4.1 National Level Plans and Policies

Rectangular Strategy-Phase IV (Royal Government of Cambodia, 2018)

Under Rectangle 4 "Inclusive and Sustainable Development" of the Rectangular Strategy Phase IV, in the Sixth Legislature of the National Assembly, the Royal Government of Cambodia (RGC) will give priority to various areas including:

- Formulating an infrastructure master plan for main cities and urban areas to support development of roads, railways and waterways as well as electricity networks, and clean water networks, especially sewage and water treatment systems;
- Increasing usage of environmental-friendly and climate-friendly technologies in physical infrastructure and socio-economic development;
- Further enhancing the beauty and services in cities and major urban areas through managing waste and sanitation; preparing pedestrian sidewalks, parking spaces, public parks; constructing riversides and dam; improving public order and lighting in the city; conserving buildings of historical value; and enhancing the quality and use of public transport in cities.

National Strategic Plan on Green Growth (National Council on Green Growth, 2013)

The RGC formulated the "National Strategic Plan on Green Growth 2013-2030" to improve green growth and focus on several strategic directions, one of which is *Green Environment and Natural Resources Management*. Under this specific direction, the RGC aims to develop infrastructure and green transport options by implementing a range of initiatives such as electric buses, renewable energy-run vehicles, and electric bicycles and motorcycles.

Financial Incentives for Low-Carbon Vehicles

At present, no financial incentives exist to support e-mobility such as subsidies and tax exemptions. Potential policy measures to promote cleaner vehicles are currently under discussion by the relevant government agencies. In 2019, the National Council for Sustainable Development (NCSD) established an inter-ministerial working group to develop a vehicle tax policy aiming at setting the vehicle tax for imported vehicles and promoting cleaner vehicles. Special tax rates to differentiate low-carbon and internal combustion-engine (ICE) vehicles are currently under deliberation. To date, the working group is developing a report on suggested adjustments for vehicle tax rates in Cambodia (MoE, 2020).

Sub-national level development and construction plans identified through focus group discussions with provincial/municipal government stakeholders include the following:

2.4.2 Sub-national Level Plans

Siem Reap Smart City Plan *(Japan International Cooperation Agency, 2021).*

Currently, the Japan International Cooperation Agency (JICA), in cooperation with the Siem Reap Provincial Administration, is carrying out a study to develop a Siem Reap Smart City Plan. This aims to transform Siem Reap city into a more sustainable and attractive urban center for local people and tourists alike. To achieve this goal, the Siem Reap Smart City Plan will seek solutions to tackle various challenges in the city by using smart technology, data analysis, and integrated efficient methods. This study will last for 22 months, starting from March 2020 to December 2021, and consists of 5 steps: 1) Assessing the current situation; 2) Proposing project-based solutions to overcome identified challenges; 3) Preparing plans to identify a roadmap for prioritized projects; 4) Implementing plans by selecting priority projects; and 5) Identifying a network.

Sustainable City Strategic Plan for Seven Secondary Cities

The municipality of Phnom Penh, jointly with the Ministry of Interior and the General Secretariat for Sustainable Development, has drafted a "Sustainable City Strategic Plan 2020-2030" which guides government, development partners and seven secondary cities, including Siem Reap, on a road map to sustainable local development, balancing economic growth with social and environmental development. The holistic plan identifies the requirements for green urban development, addressing clean energy, sanitation, waste management, mobility, manufacturing, and more. Developing environmentally friendly mobility options was among the 10 priority actions identified in the plan.

Road Construction/rehabilitation Plan in Siem Reap City

On September 8, 2020, the RGC issued a decision to establish an Inter-ministerial Committee to study and implement construction/rehabilitation of 38 roads in Siem Reap city. These 38 roads have a total length of 100 km spanning the entire city. Work started on December 12, 2020 and is scheduled for completion by December 31, 2021.

2.5 Service Planning

2.5.1 E-bus Operating Plan

It will be essential to ensure that any public transport system is capable of being adapted and developed to provide increasing capacity and an expanding route network as demand increases, with minimal change to initial infrastructure and operating concepts.

The assumptions for the various planning parameters, are summarized below. Multiple variables, such as operating speeds and dwell times, must be verified and modified as appropriate based on actual service performance once the operation has commenced.

An important element in designing the operational plan for the service is the estimation of the demand. To obtain actual demand data, it is necessary to conduct another survey focusing on passenger demand to predict actual volumes.

- **Bus Capacity**: A design capacity of 80 passengers, with a density of five standing passengers per square meter, is proposed for the 12m electric buses. It is recommended that scheduling at off-peak times should be based on maximum loads of 50 passengers.
- **Service Frequencies**: Service frequencies will depend on the capacity of the vehicles used, and on predicted passenger flows. Based on the assumptions identified in this report, it is recommended to provide six buses per hour or a 10-minute headway with peak bus capacity of 80. If demand does exceed this level, articulated e-buses with higher carrying capacity should be considered for future acquisitions.
- **Operating Speeds**: It is recommended that initial plans should be based on an average speed of 19km/hr, including stops. This should be verified as far as possible, and adjusted, if necessary, through test runs conducted before commencement of the operation, and subsequently monitored post-commencement.
- **Dwell Times**: The assumed speed of 19km/hr includes dwell times, assumed to average 20 seconds. Samples of actual dwell times for each stop on the respective lines should be measured after commencement of the operation, for use in subsequent fine-tuning of schedules.
- **Deceleration/acceleration Times at Each Stop**: The assumed speed of 19km/hr also includes deceleration/acceleration times, totaling 15 seconds for each stop. These should be verified, and adjusted if necessary, during pre-service test runs.
- **Delays at Intersections**: The assumed speed of 19km/hr also allows for delays at intersections. More accurate data will be obtained from the test runs but actual times should be monitored post-service commencement, and from time to time if there are any changes in signal phasing and cycle times or in traffic flow.

- **Layover Times**: Initially an average layover time of 6 minutes at each end of the route has been assumed. This equates to 10% of total journey time, and is typical for an urban bus operation, but may be adjusted if necessary, after commencement of the service. Due to parking capacity constraints at the terminals, it will be necessary to divide the total 12 minutes layover per cycle unevenly between the two terminals, with (possibly) 4 minutes and 8 minutes.
- **Cycle Times**: Based on the above assumptions and the result of the traffic speed survey, the cycle times for each of three lines are 98 minutes, 140 minutes and 107 minutes respectively comprising two 6-minute layovers.

Table 20: E-bus Operating Plan

Parameter	Value
Route length	Line 1: 13.66 km Line 2: 20.32 km Line 3: 15.05 km
Commercial speed	19 km/hr
Layover time	6 mins
Bus capacity	80 (12m e-buses to be used throughout the day)
Reserve buses	10%
Round trip cycle time	Line 1: 98 mins Line 2: 140 mins Line 3: 107 mins
Headway	Line 1: 10 mins Line 2: 14 mins Line 3: 10 mins
Running times	15 hours (7am – 10pm)
Fleet required at peak time	Line 1: 10 units Line 2: 10 units Line 3: 10 units
Fleet including reserve units	Line 1: 11 units Line 2: 11 units Line 3: 11 units
Annual distance per an e-bus	About 90,000 km
Daily total distance driven e-buses on 3 lines	Line 1: 2,212.92 km Line 2: 2,438.4 km Line 3: 2,257.5 km Total: 6,908.82 km
Annual total distance driven e-buses on 3 lines	Line 1: 807,715.8 km Line 2: 890,016 km Line 3: 823,987.5 km Total: 2,521,719.3 km

Lifespan BEBs	16 years (2 battery lifespan)

2.5.2 ITS Operating Plan (optional)

Through smart transport systems, electric buses would be served with absolute priority at most important junctions equipped with traffic-light controllers. From the functional point of view:

- The Bus Management System (BMS) is responsible for e-bus location and priority request generation; and
- The Traffic Control System is responsible for priority actuation and traffic-light control.

The bus priority system shall rely on two main processes, based on different communication networks and infrastructures for granting redundancy and robustness:

- Bus priority management via the private Wi-Fi communication network provides physical architecture through which priority requests can be generated and sent to the traffic-light controllers either at the local level (direct communication between the bus and the traffic-light controller) or via the central level.
- Bus priority management based on a physical infrastructure installed on the ground (i.e. inductive loops)

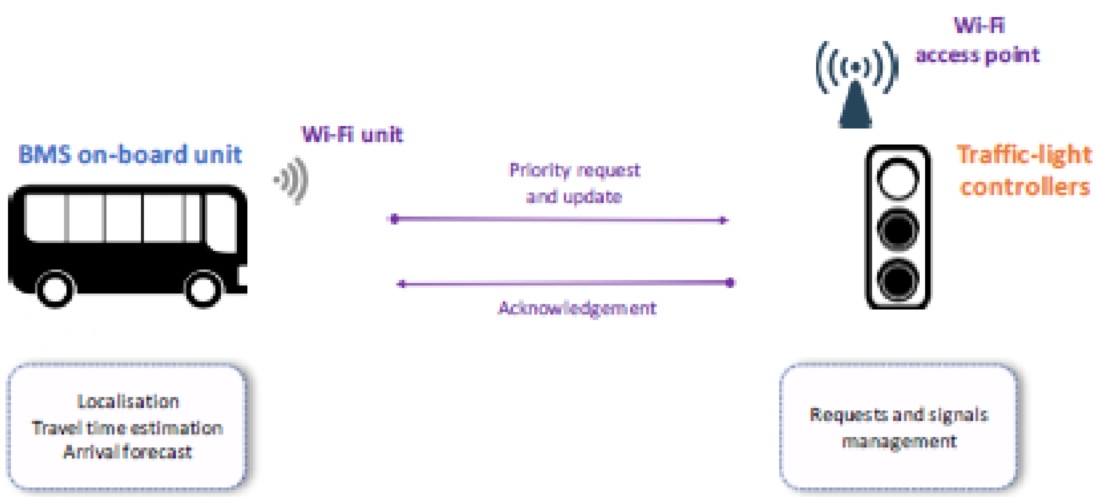


Figure 16: Bus Priority via Wi-Fi
Source: AFD report on Bus Rapid Transit Line

Under this architecture, the on-board unit is responsible for vehicle location. The functions for travel time estimation and arrival forecast are performed by the BMS central level. The priority requests/update messages are generated by the BMS central level and transmitted to the central Traffic Control system and then from the Traffic Control system to the traffic-light controllers. The transmission of the messages between the BMS central system and the Traffic Control center can be done via an optical fiber communication network.

To provide public bus users with real-time bus information and link that with relevant institutions, a Bus Information System (BIS) shall be designed. This system serves to gather bus location information, process the information into bus arrival information using algorithms, and effectively utilize the processed information. To provide the services to the public efficiently, personal information services (such as an internet homepage, ARS, mobile etc.) shall be promoted, installing bus stop terminals (BIT: Bus Information Terminal) step-by-step in consideration of the stabilized status of the BMS.

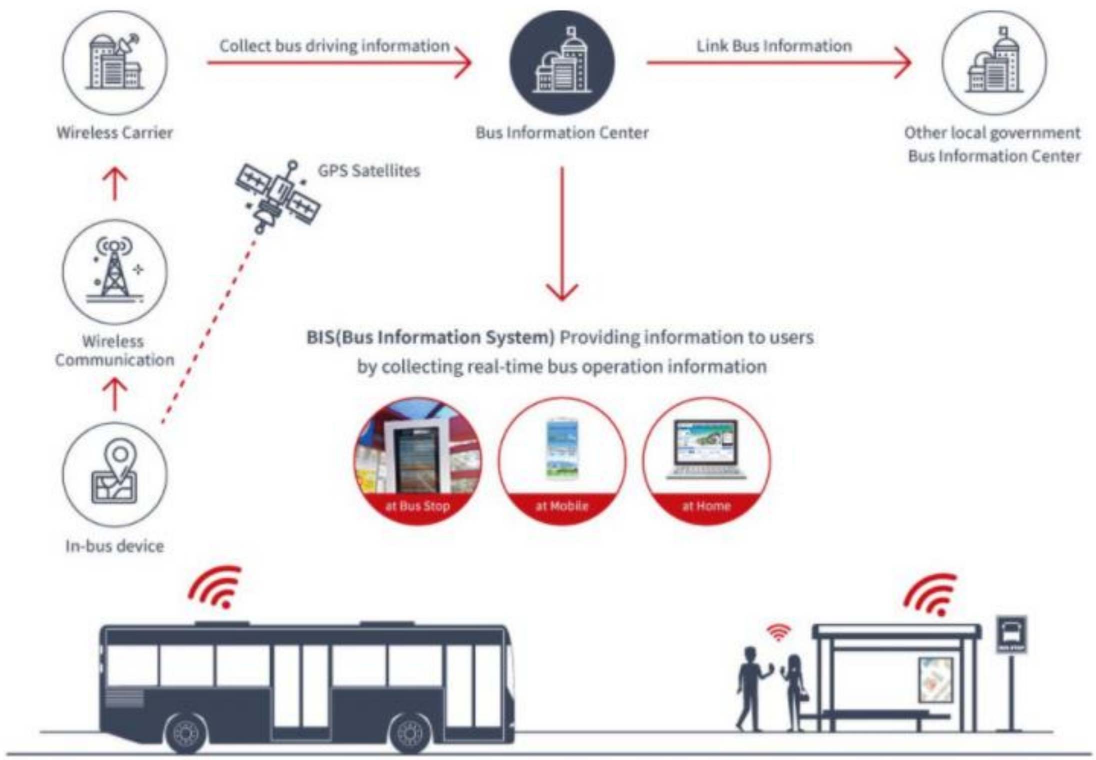


Figure 17: Bus Information System (BIS)

Source: ELECOM (BIS | eleccom)

Through introducing BIS in Siem Reap, it is expected to provide convenient services to relevant stakeholders:

- **Bus Users:** Providing real-time bus information such as bus arrival/departure times though mobile phones and terminal display equipment.
- **Bus Drivers:** Driving buses safely and controlling bus service intervals between buses through on-board equipment.

- **Siem Reap Government:** Obtaining public data and managing public services efficiently.
- **Bus Companies:** Providing efficient management conditions through real-time bus management and service information.

Chapter 3: Electric Bus Technologies

3.1 Technology Description

Buses with their own batteries (BEBs) can charged en route and/or exchanged at specific sites during the day and/or at night. There are multiple methods of charging.

a. Wire: Bus receives electricity through wires en route like a train or cable car. It can be operated without catenaries with limited range by having batteries.
b. Electromagnetic: It can be charged through the floor.
c. Plug Charge: There are two types of charging; standard and fast charging.
d. Battery Swap: It can significantly shorten charging time but requires many batteries per stop.
e. Opportunity Charge: A system permitting batteries to be charged several times during the work cycle.

The main differences between types of BEBs refers to their charging system which influences the driving range, operational flexibility, vehicle weight and passenger capacity, and vehicle versus infrastructure cost. *Figure 18* below shows the main charging possibilities.

	Charging (location / time)	Battery (capacity / weight)
(a) Wire	100% of route / -	None (0 kWh, 0 t)
(b) Electromagnetic	5~15% of route / total 30 min	Middle (-200 kWh, -2 t)
(c) Plug Charge	Final stops / 20 min ~ 14 hour	Heavy (-300 kWh, -3 t)
(d) Battery Swap	Intermediate stops / 90 sec	Middle (-200 kWh, -2 t)
(e) Opportunity Charge	Intermediate stops: 15 sec Final stops: -8 min	Light (-100 kWh, -1 t)

Figure 18: Charging Options for Electric buses

Source: Grutter Consulting adapted from Landerl, 2017

3.2 Power Supply During Movement

Wire

A bus powered by this supply method is usually called a Trolley, Tram, Streetcar, or an Electric Street Railway. It is supplied with power through an overhead wire to a pantograph mounted on the vehicle roof. The size ranges from 10m-26m. This technology is similar to a train, so is well known and has been used for decades in many countries[4]. Germany first introduced trolleybuses, but they were first commercialized in the U.S. in 1887 and distributed worldwide for half a century. However, after World War II, and the popular emergence of automobiles, trolleybuses were mostly demolished to make more space for automobiles since trolleybuses occupied too much road space.

However, after many decades of cities replacing trolleybuses with conventional petrol- or diesel-powered units, electric trolleybuses have seen a strong revival as a reliable electric source of transport without relying on heavy and costly batteries.

Trolleybuses do not have problems with operational range, have no issues with gradients and can operate in all types of climates. They do however have a limited range without catenaries (which can be expanded according to the battery incorporated in the trolleybus). Typically, an electric trolleybus has a 30-80kilowatt hour (kWh) electric battery giving it an autonomous range without a catenary of about 20-40km. Trolleybuses have a smoother ride with less vibrations than diesel units and their components allow for a 15–20-year technical life without problems[5].

[4] See e.g. http://www.trolleymotion.eu/www/index.php?L=3&id=36&land=all

[5] Clean Fleets, 2014; VBZ, Switzerland

Figure 19: 12m and 26m trolleybuses
Source: Lucerne (Switzerland), Beijing (China), London (UK), and Pyongyang (North Korea)

Electromagnetic

Electromagnetic Charging, (also known as Wireless Power Transfer) or Inductive Power Transfer (IPT)) was first seen researched in Germany in 1996. In 2009, KAIST in Korea introduced an Online Electric Vehicle (OLEV) system and began operating a university shuttle bus in 2012 with the infrastructure installed under the road on 2%-10% of the route. The developers claimed it reduced the vehicle's battery capacity by one third, made charging facilities cheaper than building a station, and presented no risk of electric shock. In 2013, KAISTs commercialized version of its bus and tram was demonstrated in Gumi and selected as one of the world's top 10 emerging technologies at the World Economic Forum (Davos Forum).

In 2011, Bombardier in Canada introduced the PRIMOVE system, which included battery packs supplied by AKASOL in Germany, and was implemented in Manheim and Berlin, Germany and in Bruges, Belgium. In 2013, Utah State University developed a spin off start-up dubbed the Wireless Advanced Vehicle Electrification (WAVE) which was adopted in Long Beach, California, and Monterrey-Salinas Transit trolleys in California, USA.

If only 5%-10% of a route requires installation, instead of construction on the road floor, it may be preferable to charge through the ceiling whenever the bus is halted at a stop (Opportunity Charge). And when the bus stops, wired charging is more reliable than wireless charging. Therefore, Opportunity Charge, described later in this report, generally means 'wired charging through the roof at a stop'. However, a 200kilowatt (kW) wireless charging system was successfully introduced by Momentum Dynamics in 2018.

Figure 20: OLEV bus and tram

Source: KAIST OLEV, 2009 (olev.kaist.ac.kr)

Figure 21: IPT Charge System

Source: A. Brecher, 2014

3.3 Power Supply During Parking

Plug Charge

One potential future power supply source, as introduced by Elon Musk in 2012, is to generate electricity from sunlight during the day (Solar City), recharge it with your home battery (Power Wall), and charge it while parked at night (Tesla Motors). This makes it possible to generate and store irregular solar power, sell the electricity at a premium price during daytime and buy the electricity at a low price during the night. The long charging time of electric vehicles can be solved by recharging at night. Stored electricity can be also used for households.

The slowest charging 'mobile connector' (3kW/h) can be used where there is no charging station, a slow charger 'Type 1' (9kW/h) can convert alternating current (AC) to direct current (DC) using the On-Board Charger, while a rapid charger 'CHAdeMo' (45kW/h) uses DC directly. These charging types are currently being standardized as a combo that can be charged at both a slow and rapid speed concurrently.

Tesla launched the Model S at 85 kWh, and the Model 3 and Model X at 44/66kWh. These personal automobiles are designed for one-hour rapid charging and slow charging for a few hours. Unlike conventional vehicles, charging time is as short as one hour, so electric vehicle companies and countries have started rest area businesses linked to cafes and shopping centers to gradually replace conventional petrol/diesel stations.

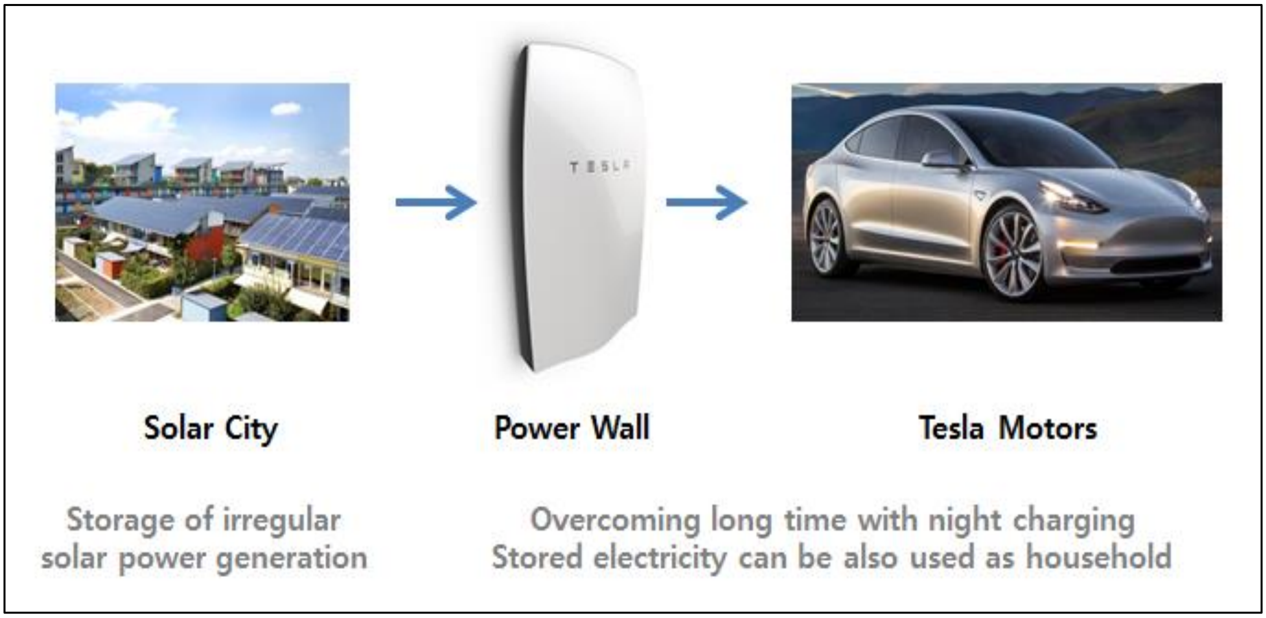


Figure 22: Vision Presentation by Elon Musk, 2012
Source: Solar City, Power Wall, Tesla Motors

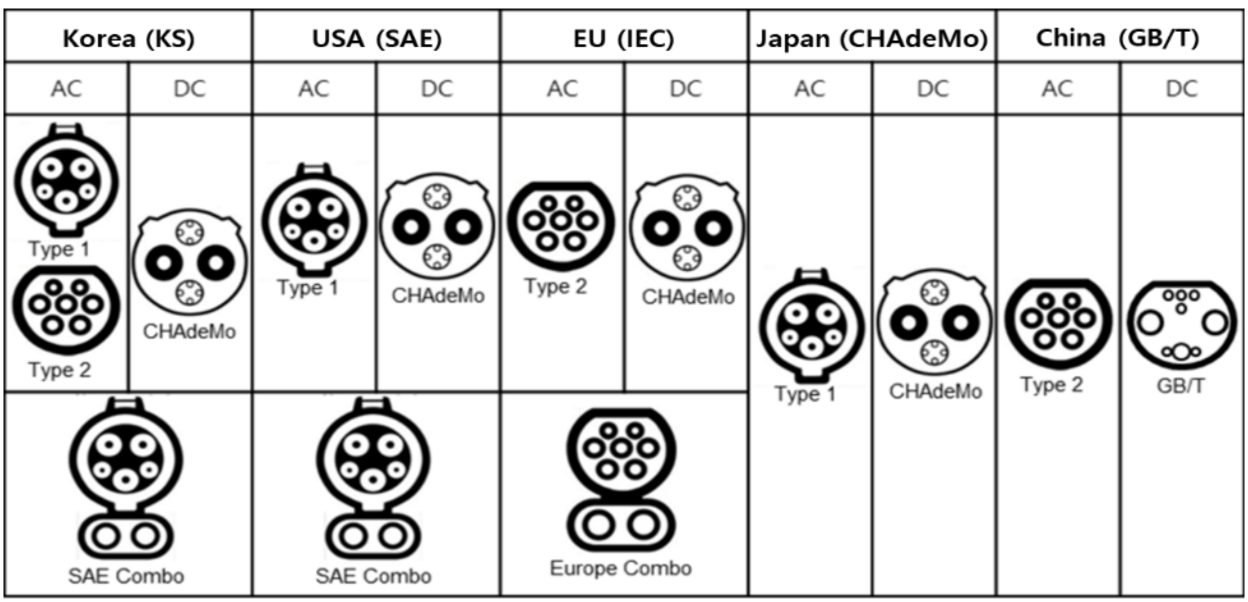


Figure 23: Standardization of Electric Vehicle Charging Terminals

In a 12-metre-long bus, typical battery capacities in the order of 100-350kWh allow for a driving range of 100-300km. This results in an additional bus weight of 2-4 tons. Typical overnight charging requires 4-6 hours with 15-50kW chargers (such as typical CHAdeMo charger).

Recently, fast charging has rapidly grown in popularity due to the availability and lower prices of fast-chargers with power ratings of 150-450kW. Buses can be charged in 15-30 minutes from 20-

100% depending on the battery capacity of the bus, the charging unit, and the number of power sockets on the bus. (-> Opportunity Charge)

Figure 24: Slow AC Chargers (Type 2) for BEBs

Source: Beijing, Tianjin

Battery Swap

In 2013, Elon Musk first introduced the Battery Swap system, with the major advantage that a battery can be replaced in 90 seconds. The concept did not gain traction in the U.S. market however as consumers did not want to share batteries, so the project was withdrawn after just two years.

Five years later in 2018, NIO in China introduced a similar system. To overcome consumer reluctance on sharing batteries, NIO provided a leasing service whereby batteries were not initially included in the vehicle. Both Tesla and NIO had this monthly leasing service in common with their business models. NIO installed more than 450 stations in 19 cities in China, with 40% of them located in the capital Beijing. Battery Swap Stations require 200 batteries per day to make profit, but only 150-160 are being currently being replaced per day.

Buses have a similar battery capacity and configuration to enable fast charging. However, instead of charging the batteries in the bus, they are removed by robots and replaced with new units. This takes around 10-20 minutes i.e., a comparable time to fast charging. Battery swap stations are very expensive, buses must return to these stations (although fast-charging mobile equipment is also available), many batteries are required, and battery swap systems are not standardized and are thus locked-in with certain producers. As a result, many cities have not adopted this system though the Chinese government continues to invest in this technology.

Figure 25: Automated Batter Swap System for Car

Source: NIO, 2018

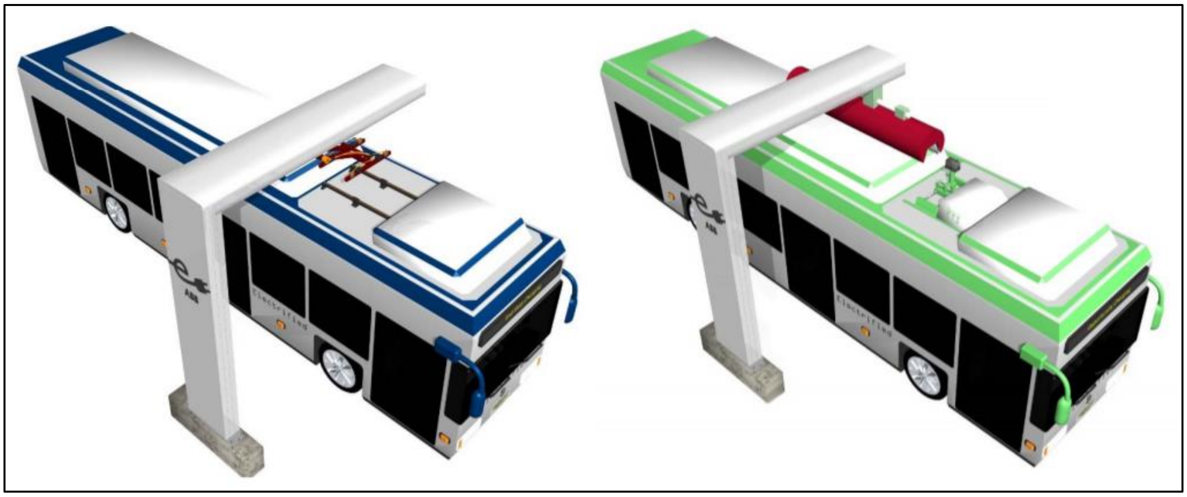
Figure 26: Automated Batter Swap System for BEBs

Source: Zhengzhou, China

Opportunity Charge

Opportunity Charge charges the bus en route either at charging points located along the bus circuit or at initial and final stops. At the intermediate stop, it is possible to charge for only about 15 seconds, (the stopping time), while at the end point, the bus can be charged for 6-10 minutes. This is specialized form of fast charging taking place at the end of or on a route. Buses can be equipped with minimal batteries, but the system reduces operational flexibility as buses need to operate on equipped routes. Open system configurations allow for different types and brands of buses to be charged at the same site and in the future also potentially other vehicles e.g., urban trucks.

There are two topology types for this technology: Inverted Pantograph and On-board Pantograph. The inverted type simplifies the bus and raises the price of the charging network. The on-board type simplifies the charging network and places significant restrictions on the design structure of the bus and requires charging at the correct location. The on-board type requires less physical batteries in the vehicle itself.



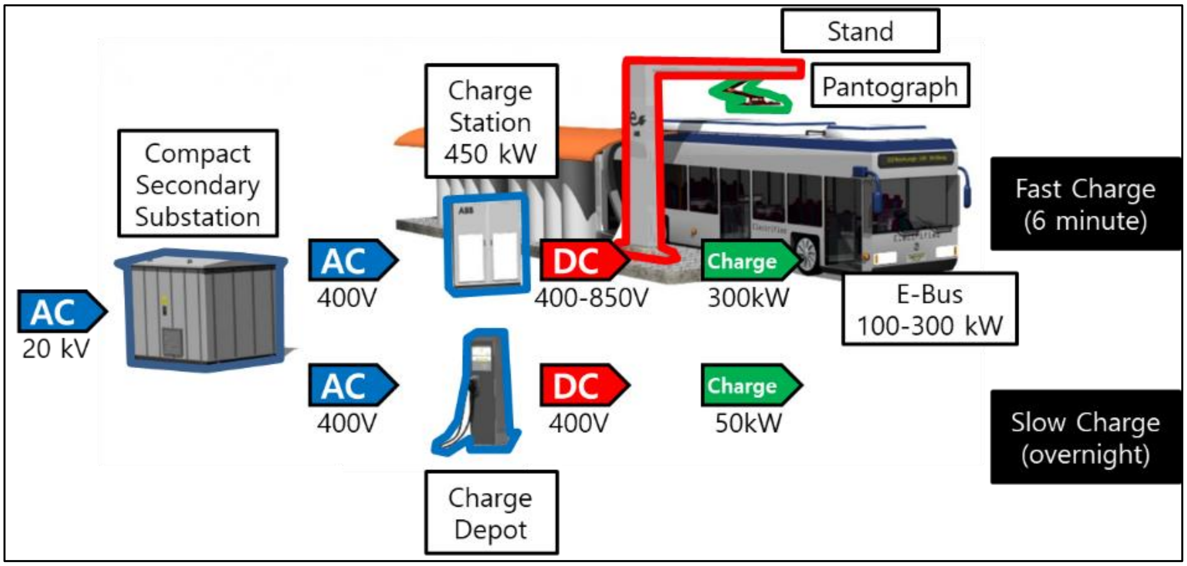


Figure 27: Opportunity Charge System (Inverted/On-Board)

Source: ABB

3.4 Cases

London (UK) operates hybrid buses that are recharged at end stations along the route[6]. The main characteristics of the system being tested with four buses are:

a. Route of 11km (one way) with 7-12 minutes headway between buses.
b. Hybrid double-deckers buses with consumption of about 2 kWh in electric mode.
c. Two rapid-charge points with inductive loading of 60kW for 7-14 minutes sufficient to operate on with 40% electric mode with overnight charging at the bus depot. The wireless charging system is based on installing charging equipment into the road (IPT). This is used also on routes in Turin, Genoa (Italy), and Mannheim (Germany).

[6] ZeEUS, 2014a

Stockholm (Sweden) operates systems similar to those in Luxemburg, Charleroi, Namur or Goteborg, with hybrid buses that are recharged at the end stations of the route[7]. The main characteristics of the system which is being tested with nine buses[8] are:

a. Route of 8.5km (one way) with a requirement of nine buses during peak hours.
b. Plug-in hybrid buses of 12m with 9kWh of usable energy from the batteries; the buses used in Luxembourg have a battery capacity of 76kWh; power usage approx. 1.1kWh/km without AC or a heating system operated by the diesel engine (5l/100km used for heating);
c. Two quick opportunity load points (1 at each end station) with 150kW and 3-6 minutes of recharge time. With each minute of load the bus can travel approximately 1km in electric mode: during the night slow charging with 11kW and a duration of 3-4 hours.

Figure 28: Opportunity Charge System in Goteborg and Luxemburg

Geneva (Switzerland) operates an ultra-rapid charging system called "flash charging" which was tested for one year and started commercial operations on a full 12km route with around 30 stations, a headway of 10 minutes and 10,000 passengers per day (see *Figure 29* below). The system operates with 12 articulated fully electric 18m buses using a super capacitor. The system has ultra-rapid charging at 13 stations with 600kW and 15-20 seconds of "flash charging". At the end of the route the bus is charged for 4-5 minutes (200kW charger) thereby fully charging the supercapacitor. In the bus depot another four slow chargers of 45kW have been installed which require 30 minutes of charging time and which allows the bus to cover the distance from the depot to the starting point of the route without further charging. The flash stations are connected to the 50 kilovolt-ampere (kVA) electricity network and have a 3kWh storage unit for smoothing peaks in consumption.

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[7] ZeEUS, 2014b and personal communication with Volvo

[8] The system currently being established in the cities of Charleroi and Namur in Belgium includes 12 charging stations and 90 hybrid buses.

Figure 29: Flash Charging of Electric Buses (TOSA)

Barcelona (Spain) operates with articulated electric buses that are recharged at the end stations along the route[9]. The main characteristics of the system being tested with two buses are:

a. Route length of 7.5km (one way, return 15km) with 1% slope on average and five minutes of headway between buses.
b. Electric 18m buses with AC, but without heating and with 125 kWh of batteries.
c. Electricity consumption of 2.5-3.9 kWh/km; two rapid opportunity charging points (one at each end station) with 400kW pantograph power and a recharge time of five minutes; slow recharge during the night with a 50kW charger and a duration of 3.5 hours.

China offers two types of opportunity charge system. China's high-speed train manufacturer, China South Locomotive & Rolling Stock Corporation (CSR) says their system only requires 30 seconds for the batteries to be fully charged after which the bus can operate for around 5km.

a. Option A recharges the bus at the end stations using hybrid or electric buses and operating 50-100% in electric mode according to length of the route, bus type and its electricity consumption, battery capacity and recharge time. In Europe, an open standard has been established for opportunity charge systems which enables buses of different brands, technologies (BEB or hybrid) and sizes to use the same chargers (OppCharge)[10].
   Option B with ultra-fast recharging with short loads at each or every second station ("flash charging" of 15-20 seconds whilst passengers board and de-board the bus) and a few minutes recharge at the final station using full electric buses with a super capacitor or a small battery.

It is estimated that 98% of electric buses run in China. Only in China have there been fleets of more than 100 BEBs operating for several years in several cities. In Europe and the U.S. however, there are mainly pilot fleets with some units recently expanding to commercial fleets with more than 20 or 30 buses. BEBs are used for short routes, with limited slope and moderate passenger

[9] ZeEUS, 2015
[10] See https://www.oppcharge.org/

loads. BEBs operate between 30% and 55% of the average distance driven by conventional vehicles. This clearly shows their usage for lower daily distance driven with lower passenger volume.

Santiago (Chile) conducted electric bus demonstration projects in 2011 and 2013 and continued through 2017, a pivotal year in terms of electric bus pilot projects. In November 2017, Metbus, one of Santiago's private bus operators, partnered with Enel, an Italian utility company, and BYD to bring two electric 12m BYD K9FE buses to operate under regular service in Santiago. The two buses ran for a year with five trained drivers on route 516, which takes approximately 4–4.5 hours to complete.

a. Covered 105,981km and moved more than 350,000 passengers with an availability ratio of 99.23% (1,665 return legs were completed, 13 return legs were not).
b. Operating costs at USD 0.10/km based on a USD 0.10/kWh price and an energy consumption of 1.006 kWh/km, in comparison with a diesel reference bus of which 0.5 liters/km energy consumption operates at a cost of USD 0.86 per liter.
c. As a result of this pilot, Metbus worked with BYD and Enel X, an Enel subsidiary, to scale up the operation by adding an additional 100 BYD K9FE units in 2019.

In the case of **Kolkata (India)**, the Department of Transport and the Government of West Bengal has already introduced 80 electric buses under Phase-I of the FAME scheme (FAME-Initiative), operating in and around the city. The initiative began with 20 buses in February 2019 and procured a further 10 buses which were introduced in January 2020. These electric buses have been distributed among the existing 10 depots, located at different places within the city and one at the seaside town of Digha. The implementation of the electric bus program in Kolkata has had a great impact on all aspects related to public mobility.

a. The reliability of the electric bus operation improved by up to 98% despite several initial challenges.
b. Overwhelmingly positive responses have been received from the e-bus customers in terms of comfort and reliability on each trip.
c. Furthermore, the cost of Li-Ion batteries has been reducing drastically over the last few years and it is expected to drop further in the next 2-3 years which will positively impact the viability of e-buses using such batteries.
d. It is expected that annual CO2 emissions will reduce by 3,094 tons, considering a daily round trip of 100kms per bus and an emission factor of 1.19Kg CO2 emissions/km per bus.

At present, 5% of the total conventional bus fleet has gone electric in the Kolkata. The e-buses are operational under 12 different routes with an average distance travelled per route equal to 20km.

3.5 Low-Carbon Technology Option for a Siem Reap Bus System

This report has demonstrated the use of a mix of technologies according to route type, daily distance driven and transport capacity requirements. Trolleybuses can be used for all routes where no route short- or medium-term route changes are expected, while BEBs can be used for lower passenger volume routes and lower daily distance driven. Opportunity charge systems have flexibility for usage on demanding and less demanding routes. Hybrid buses can be used on all types of routes, whilst plug-in hybrids have more limitations concerning size and speed driven. Hybrids combine both an electric motor and a gasoline engine, with their gasoline engine primarily operated as the power source. Therefore, neither the gasoline engine nor the electric motor works as strongly as they do in conventional gasoline or electric cars. Hybrids have more machinery than conventional and electric cars, which adds extra weight and reduces fuel efficiency.

Considering the current state of transport in Siem Reap, it is recommended to introduce 12m BEBs with a plug charge system on the proposed three lines. BEBs can be effectively operated on the proposed three lines, which are low in demand and with less than 200km daily distance driven[11]. Demand for a new transport service is difficult to predict and numerous attempts to estimate demand for the suggested three lines have been hampered due to the impact of COVID-19. Based on current traffic volume and movement, therefore, it is suggested to introduce 12m electric buses on the three lines. The option of BEBs with a plug charge system is usually more economical in comparison with other option, including opportunity charge systems and trolleybuses. The 250kWh high-capacity battery is appropriate for routes that consume high amounts of electricity with frequent traffic congestion or slopes, as well as for coach services. If a bus is constantly running at 73 kph, it can travel up to 290km per charge. With regard to short-distance routes, it allows buses to run three to four times in a row without charging. In this regard, the 250kWh battery capacity of BEB is able to cover the three lines, which have an average slope of 1.5° and less than 290km of daily distance per bus based on headway and route length. The recommended BEB specifications are as follows:

Table 21: Recommended BEB Specifications

Specifications	Values
Capacity (pax)	80
Overall length (mm)	12,000
Battery	Lithium polymer
Battery Capacity (kWh)	250

[11] Higher daily distances driven are also possible to operate with BEBs but require either multiple charging during the day or very large battery sets on the bus, both of which result in a significant increase of costs.

Chapter 4: Environmental and Financial Assessment

4.1 Environmental Impact Assessment

4.1.1 Emissions Value

This section will analyze the environmental impact of the below emissions:

- GHGs including direct (tank-to-wheel or TTW) as well as indirect emissions (well-to-tank or WTT). Black Carbon (BC) emissions are included as indirect emissions.
- Local pollutants including $PM_{2.5}$ and NO_X resulting from engine combustion.

Direct Greenhouse Gas Emissions

GHGs, included under the United Nations Framework Convention on Climate Change (UNFCCC), are CO_2, methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6) and trifluoride nitrogen (NF_3). Relevant for the transport sector are only CO_2, CH_4 and N_20. However, according to methodologies for determining emissions from the transport sector of the UNFCCC, N_2O emissions are very marginal. In this report, only CO_2 emissions are included for assessment[12].

Black Carbon

Increased particle emissions result not only in worsening air quality but also in higher BC emissions. A scientific assessment of BC emissions and impacts found that these are second to CO_2 in terms of climate forcing. BC is on average 2,700 times more effective on a mass-equivalent basis than CO_2 in causing climate impacts within 20 years, and 900 times more effective within 100 years[13]. BC is part of PM from diesel engines. The GHG impact of BC is determined based on the mass of $PM_{2.5}$ emissions (using the European emission model COPERT), the fraction of BC in $PM_{2.5}$ and the GWP_{100} (Global Warming Potential 100 years) of BC.

Indirect GHG Emissions

The most important indirect emission is due to electricity production including transmission and distribution losses. Electricity-based emissions are based on the Combined Margin approach used by the UNFCCC for climate change projects. Indirect emissions are included technically as WTT (Well-to-Tank) and not as TTW (Tank-to-Wheel) emissions.

Indirect emissions also include also WTT emissions as not only electricity causes upstream emissions but also fossil fuels. A standard mark-up factor per fossil fuel type is used to estimate

[12] IPCC, 2006, chapter 3

[13] see Bond, 2013 or World Bank, 2014

the GHG upstream impact of fossil fuels based on the UNFCCC to account for emissions caused upstream by fossil fuel extraction, refinery, and transport.

Local Pollutants

Local pollutants $PM_{2.5}$ and NO_x are considered due to their impact on local air quality. Only combustion-based emissions are included. Particle emissions caused by tires or brakes are not considered. Both pollutants are determined based on the emission category of the vehicle and emissions per unit of distance driven using the European emission model COPERT.

Summary Default Values

Table 22 below summarizes default values used within this report.

Table 22: Default Calculation Values

Parameter	Description	Value	Source
NCV of diesel	Net Calorific Value of diesel	43.0 MJ/kg	IPCC, 2006, table 1.2 2014 United Nations Energy Statistics Yearbook
EF_{CO2} of diesel	CO_2 Emission Factor of diesel	74.1 gCO_2/MJ	IPCC, 2006, table 1.4
GWP_{100} of BC	Global Warming Potential 100 years of BC	900	Bond, 2013; IPCC, 2013, Table 8.A.6
GWP_{100} of CH_4	Global Warming Potential 100 years of methane	28	IPCC, 2013, Table 8A
WTT MF_D	Well-to-tank mark-up factor for diesel	23%	UNFCCC, 2014, table 3
EF_{elec}	Electricity grid factor of Cambodia	0.7 kg CO_2/kWh	IEA, 2017 (ADB, 2019)

4.1.2 Baseline Diesel Bus

The baseline bus is defined as a bus that would be purchased under a Business as Usual (BAU) scenario. This is not the current bus type operating in Cambodia but reflects a new bus which would be purchased today in compliance with all legal requirements and in accordance with standard current business practices.

Table 23: Baseline Bus Parameters

Parameter	12m Bus
Passenger capacity	80

Euro standard[14]	IV
Annual distance driven	90,000 km
Average daily distance driven[15]	273 km
Commercial lifespan of bus[16]	15 years

Passenger capacities of buses vary between countries and cities depending on the number of seated versus standing passengers or the maximum number of passengers per sqm. However, the values used are common in many cities worldwide.

The bus investment cost can have large variations depending on bus type used including criteria such as high floor, semi-low floor, or low floor buses. In this report, the bus investment cost is calculated based on the available price data of diesel buses manufactured in Korea, China, and those sold in Cambodia. The cost is adjusted reflecting the current import tax rate for buses in Cambodia.

Table 24: Cost for 12m Diesel Bus (all with AC)

Bus	Cost (USD)	Note
Hyundai Motors, Korea	104,399/112,146	Depending on different suspension options
Zyle Commercial Vehicle, Korea	103,151/132,181	
Yutong, China	95,000	
Hyundai Motors, Korea	200,000	Based on market research in Cambodia (inclusive of all taxes and charges)
Average	**124,480**	
Average (after tax @ 77.1%)	**194,753**	Includes Customs Tax/Import Tax, Special Tax, and VAT (provided by General Dept. of Customs and Excise)

Table 25 shows the environmental impacts of a baseline diesel bus.

Table 25: Environmental Impact of Baseline Diesel Bus

Parameter	12m Bus	Source
Diesel consumption	46 l/100km	Average BRT buses[17]

[14] Based on 50ppm sulphur diesel as of 1.1.2018 (currently much higher level); 50 ppm sulphur in diesel corresponds to Euro IV emission standard
[15] Based on 330 operational days
[16] ADB, 2019
[17] Includes BRTs of Barranquilla, Bogota, Cali, Guadalajara, Johannesburg and Zhengzhou; include operations with AC

TTW CO_2 emissions[18]	1,237 g/km	Calculated
WTW incl. BC [19] CO_{2e} emissions	1,597 g/km	Calculated
$PM_{2.5}$ emissions	0.112 g/km	COPERT, 2020, Tier 3 with 19km/h, Value for Cambodia
NO_x emissions	6.96 g/km	

4.1.3 Environmental Impact of Introducing a Battery Electric Bus

Table 26 below shows the energy consumption of 12m BEBs with a plug charge system, which is recommended as the most optimal technology option for the suggested bus lines.[20] There is a big fluctuation in energy consumption depending on bus types, route and weather conditions. The level of energy consumption of BEBs continues to fall as technologies advance. *Table 26* below shows energy consumption of BEBs produced by Korean and Chinese manufacturers as of March 2021.

Table 26: Electricity Consumption of 12m BEBs with Plug Charge System

City/Country	Electricity consumption (kWh/km)	Note	Source
Korean manufacturer	0.72~0.98	Min 0.72, Hyundai 'Elec-City' 0.81, Max 0.98	03/2021 Korean Low-emission car homepage (ev.or.kr)
Chinese manufacturer	0.85~1.11	BLK 'Elenus' 0.85, BYD 'K9DA' 1.11	
Median value (w/o AC)	**0.85**		
Median value (w/ AC)	**1.28**		

BEBs are sensitive in energy consumption to gradients, high load and very low or very high temperatures which require strong cooling or heating. Electricity consumption in these months can be 50% higher than during moderate temperature months without cooling or heating requirements.

Table 27 below summarizes the environmental impact of BEBs compared to diesel Euro IV units.

Table 27: Environmental Impact of BEBs Compared to Euro IV Diesel Bus (per annum)

Parameter	12m bus
CO_2 emission reduction TTW (tons)[21]	111

[18] Tank to Wheel: Combustion emissions

[19] Well to Wheel: Includes TTW and upstream emissions from fuel extraction, refinery and transport

[20] For this Chapter, BEB means the BEB option with the plug charge system.

[21] Excludes emissions of electricity production

CO_{2e} emission reduction WTW incl. BC (tons)	62
$PM_{2.5}$ reduction (tons)	0.0101
NO_x reduction (tons)	0.627
Noise impact[22]	10 dB lower (50% lower)

Source: Calculations by GGGI, using methodologies provided by Grutter Consulting

When considering the lifecycle emissions of BEBs, the type of battery used and the assumptions, e.g., source and form of raw material extraction, have a strong influence. The subsequent use of batteries also influences lifecycle calculations. In China, for example, batteries used in BEBs are repurchased by the manufacturer or third parties and are used for stationary applications, for example, to balance differences in the use and generation of renewable energy. Batteries can be used without problem for another 20 years in this function as they still retain more than 50% of their capacity, whilst for vehicles the batteries are removed if their retention capacity drops below 70-80%[23].

The difference in lifecycle emissions in the production phase from BEBs to conventional diesel buses is minimal. A life cycle analysis based on the EIO-LCA model (Carnegie Mellon University, USA) reveals marginal differences between a conventional diesel bus and a BEB in terms of environmental impact concerning GHG, PM_{10}, NO_x, SO_2 emissions and water use in the production phase of the bus and during its maintenance. The environmental impacts of the production and maintenance phase in all cases are much lower than, for example, the WTT emissions caused by energy production[24]. Cooney's study (2013) also confirms that the main emissions of BEBs, as far as GHGs are concerned, are produced by electricity generation and not by bus and battery production.

4.2 Financial and Economic Assessment

4.2.1 Methodology

Methodology for Financial Assessment

Financial and economic impacts are assessed based on the total cost of ownership (TCO) approach i.e., they include CAPEX in buses and required infrastructure as well as OPEX of energy and maintenance during the lifespan of buses.

The financial assessment is conducted to calculate the incremental investment and cost savings of the BEB option compared to the baseline diesel bus. A relative calculation is made as multiple

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22 http://new.abb.com/future/de/tosa; A comparative measurement in Germany of a Euro VI diesel bus with a BEB revealed a difference of 16 dB when departing from the bus-stop and 8 dB for bus transit (http://news.emove360.com/public-comparison-e-bus-much-quieter/?lang=e)

23 Source: BYD

24 Ercan, 2015.

cost elements are not related to the bus technology used but common regardless of the technology used (e.g., salary of drivers).

Capital expenditure (CAPEX) includes bus investment costs and the required additional infrastructure (e.g., charging stations) plus partial replacement costs (e. g. batteries). Potential differences in the commercial life-span relative to the bus technology and potential differences in bus availability are also included in calculations. Operational expenditures (OPEX) included are maintenance and energy costs which differ relative to the technology used.

The financial net present value (FNPV) is to assess incremental CAPEX and OPEX (savings) for purchasing a BEB relative to a diesel unit. FNPV is calculated using the Weighted Average Cost of Capital (WACC) as a discount rate. The financial internal rate of return (FIRR) represents the expected annual growth rate of an investment and is compared with WACC as a hurdle rate to determine if the incremental investment is profitable (if FIRR>WACC) or not. WACC is calculated as below.

$$WACC = r_e \times W_e + r_d \times W_d \times (1 - T_c)$$

where:

WACC	Weighted Average Cost of Capital
r_e	Cost of equity
W_e	Percentage financed with equity
r_d	Cost of debt
W_d	Percentage financed with debt
T_c	Corporate tax rate

Table 28: Parameters to Determine WACC

Parameter	Value	Source
Cost of equity (r_e)	16.24%	UNFCCC, CDM Methodological Tool Investment Analysis Version 9.0, 2018; value for the transport sector in Cambodia
Percentage financed with equity (W_e)	30%	Typical value used for credit finance of buses
Cost of debt (r_d)	9.7%	Average lending rate of USD and KHR-denominated loans in 2019 (MSP, 2019)
Percentage financed with debt (W_d)	70%	Typical value used for debt financing of buses
Corporate tax rate (T_c)	20%	Profit Tax; https://taxsummaries.pwc.com/cambodia/corporate/taxes-on-corporate-income
WACC	10.3%	

The resultant value for the WACC is 10.3%.

For diesel and battery costs real price trends are included. The actual cost of batteries has an impact on battery replacement costs in e-buses. However, the impact is not so large due to the following factors:

- Batteries are only replaced after about five to eight years. The real cost of batteries is rapidly decreasing, and with the discount factor used (10.3% corresponding to WACC) 1 USD in eight years[25] is equivalent to USD 0.46 of today or just the discount factor reduces the impact of battery replacement by 56%.
- Battery cells only represent about 40% of the cost of the complete battery pack, so an impact on cell cost reduction is not equal to a proportional reduction of the complete battery pack[26].

Table 29 below shows core parameters used for financial and economic calculations.

Table 29: Parameters for Financial Calculations

Parameter	Value	Source
WACC	10.3%	See Table 28
Diesel Price	0.8 USD/l	03/2021; 3,350 KHR/liter https://www.globalpetrolprices.com/Cambodia/diesel_prices
Electricity price	0.15 USD/kWh	03/2021; 610 KHR/KWh https://www.globalpetrolprices.com/Cambodia/electricity_prices
Compound annual growth rate (CAGR) real oil price	3.6%	World Bank 04/2019, real USD prices for 2030 70 USD/bbl; price Dec 2020 49 USD/bbl based on https://ycharts.com/indicators/average_crude_oil_spot_price
CAGR real price electricity	0%	Assumption
CAGR real cost batteries	-20%	Lithium-ion battery price survey results (Bloomberg New Energy Finance, 2019)

Marginal abatement costs per tCO_{2e} are the costs of reducing one ton of CO_{2e} and calculated based on WTW including reduced Black Carbon emissions. Marginal abatement costs are calculated based on:

- The NPV which reflects the discounted lifetime costs or benefits of the incremental investment. This value will depend significantly on the discount value. For this report the discount value chosen is the WACC.
- The cumulative net benefit of the incremental investment not discounted (equivalent to the NPV with a discount value of 0).

Marginal abatement costs will vary between the non-discounted and the discounted value with changes of the discount rate.

[25] Typical replacement age of batteries
[26] Landerl, 2017.

Methodology for Economic Assessment

While the financial assessment is conducted to compare incremental costs and savings of low-floor e-buses with those of diesel vehicles, the economic assessment is carried out from the perspective of the entire economy and evaluates overall benefits of the project to society as a whole. For the purposes of this report, the economic impact of the reduced emissions is calculated by assigning a monetary value to the emissions of $PM_{2.5}$, NO_x, and CO_2. The values are taken from an IMF (International Monetary Fund) publication. The values of pollutants calculated by the IMF are based on local levels of pollution at the ground level and the impact on health and costs caused by this type of pollution.

The global warming externality cost is expressed through the social cost of carbon (SCC), which is an estimate of the economic damages associated with an increase in CO_2 emissions. The calculation value used by the IMF for determining global warming damage for fuels is USD 35 per tCO_2 uniform for all countries based on 2007 USD[27] . This corresponds to USD 43 per tCO_2 using 2020 USD[28].

Table 30 below shows economic emission values used.

Table 30: Economic Emission Costs

Parameter	Value	Source
$PM_{2.5}$	17,327 USD per ton	IMF, 2014, Annex 4.2. Converted to 2020 USD value
NO_x	122 USD per ton	IMF, 2014, Annex 4.2. Converted to 2020 USD value
CO_2	43 USD per ton	IMF, 2014. Converted to 2020 USD value

Source: IMF, 2014 (USD of 2020)

For economic calculation, the value of reduced emissions is included as annual savings. An economic discount rate of 9% is used to calculate the NPV from the economic perspective (ENPV). The ADB guidelines for economic analysis (2017) provide a discount rate of 9% as the minimum required EIRR for an economic analysis for all investment projects such as transport, energy, urban development, and agriculture.

4.2.2 Financial and Economic Impact of Introducing Electric Buses

Table 31 below shows the incremental investment of a BEB.

Table 31: Incremental Investment of 12m BEB Compared to Diesel Bus

Country	Incremental Investment	Note

[27] IMF, 2014.

[28] http://stats.areppim.com/calc/calc_usdlrxdeflator.php

	Compared to Diesel Bus	
US (Average)	83%	300 kWh battery; 09/2020
EU (Average)	65%	324 kWh battery; 01/2016
GGGI study for Lao PDR[29]	64%	Value used for pre F/S
Median	**65%**	

Manufacturers generally guarantee a service life of 5-8 years for batteries. Based on this useful effective life, a calculation is made for replacement of batteries after 8 years of average use. The calculation includes the residual value of used batteries and the updated cost of new units based on average price decrease of batteries due to technological advances. The calculation is based on an energy consumption of 1.28 kWh/km (with AC) and a minimum state of charge (SOC) which needs to be maintained in order to avoid permanent damage of 20%[30].

In diesel buses, the costs of a fuel station are not included as calculations are performed with the diesel selling price at the station, i.e., this price already includes the costs of commissioning and operation of a service station. In the case of electricity, either the operator can invest in charging infrastructure or the electricity company. If the latter owns the chargers, they will, in general, apply a service charge to the electricity price[31]. *Table 32* below shows the estimated investment costs of charging systems excluding land and design costs.

Table 32: Other Investments for Electric Buses

Parameter	Unit	Value	Source
Slow charger station (50kW,1 unit)	USD	6,000	Average cost Zhengzhou, Jinan, Tianjin (charger with 2 nozzles; thus 50% of investment of 1 charger); Europe 5-25kUSD; USA part of bus cost; Source: Beijing, Tianjin, Jinan bus operators; Landerl, 2017; CARB, 2016
Rapid charger station (200-300kW, 1 unit)	USD	60,000	USD 35-40K for 200kW
Number of buses per slow charger	bus/unit	1	
Number of buses per rapid charger	bus/unit	0.2	2 rapid chargers per 1 route; 10-12 buses per route
Lifespan chargers	years	20	CARB, 2017
Lifespan bus	years	16	Less vibrations relative to diesel bus
Investment battery replacement	USD	25,000	Based on 250 kWh battery set and 100 USD/kWh

[29] GGGI, 2019.

[30] The state of charge represents the theoretical amount of electrical energy available in the battery. If the SOC of a battery is 100%, it means that there is a maximum theoretical amount of electrical energy which can be used. If the minimum SOC for the battery is 20% we can only use 80% of the theoretical maximum.

[31] The company might also put this cost onto the general electricity price if policy wise such a decision is taken.

Residual battery value	%	20%[32]	BYD, for stationary applications

Maintenance costs vary considerably, ranging from half the maintenance costs of a diesel bus to higher costs than a diesel unit[33]. In theory the maintenance costs of BEBs should be well below diesel buses due to having fewer moving parts. However, in practice there are some components which increase the cost for BEBs such as the demand for higher qualified personnel, more expensive spare parts and longer delivery times for spare parts increasing standstill times of buses. Operators of large fleets of BEBs have noted a 20% lower mileage of tires compared to diesel buses, due largely to the increased weight of a BEB[34]. On the other hand, brake maintenance costs are lower, and no oil or filter changes are required. Large BEB operators still experience a larger number of failures of BEBs compared to diesel units. However, in the medium term, maintenance costs should be lower than for diesel buses.

The general availability of BEBs is not yet at the level of diesel buses. Although the propulsion system is technically simpler, there remain multiple issues with the battery management system as well as problems with elements that are not directly related to electrical parts such as faults in the AC system, door failures, and suspension failures, among others. For repairs, BEBs tend to remain in the workshop longer due to lack of or difficult in sourcing spare parts. BEB availability is estimated to be 5% lower than diesel units by CARB (2017)[35], up to 20% lower by VDV of Germany[36], while in Fuzhou with a fleet of more than 200 BEBs there were 40 cases of failures on average per BEB during the year versus 37.4 for diesel buses, or 1% lower availability[37].

Table 33 below shows the main financial profitability calculation of a BEB. The result shows that introducing one BEB unit causes incremental capital costs for a bus and infrastructure, but long-term cost savings for energy and maintenance can recover the initial investment compared to operating a diesel unit. The NPV of incremental cost saving over 15 years is USD 60,336 (per bus), and FIRR is 17%, which is higher than the cost of invested capital (WACC at 10.3%).

Table 33: Financial Profitability of a BEB (12m)

Parameter	Value
Incremental CAPEX bus	145,382 USD

[32] Value for new batteries at the moment of purchase of new units
[33] see Landerl, 2017 with a range of 50% to 100% of diesel buses; CARB, 2016 estimates on average 30% lower maintenance costs (see CARB, TCO); Fuzhou has 20% lower maintenance costs; Tianjin has 20% higher maintenance costs of BEBs
[34] E.g. Tianjin with 1,350 BEBs of 10.5 y 12m since 2013
[35] Based on Foothill Transit with 8 12m BEBs and a bus availability rate of 90% between 2014-2016 (NREL, 2017, Table ES-1)
[36] http://www.n-tv.de/wirtschaft/Elektrobusse-bleiben-Randerscheinung-article19739046.html
[37] The similarity of bus availability values of BEBs and diesel units is at least partially due to the large fleet of BEBs and the proximity of the manufacturer.

Incremental CAPEX infrastructure per bus	18,000 USD
Annual energy savings	15,570 USD
Annual maintenance savings	3,600 USD
NPV of incremental cost/saving	60,336 USD
Incremental cost per km	-0.04 USD/km
Incremental FIRR	17%
Marginal abatement cost per tCO_2 with/without discount factor (WTW approach)	-65/-321 USD/tCO2

The major sensitivity of results would be related to the projected diesel price increase and the incremental bus CAPEX.

Table 34 below shows the result of an economic assessment of a BEB. The result shows that the present value of total economic benefits calculated from the economic value of emissions reduction exceeds that of total costs (CAPEX + OPEX). The economic NPV of incremental economic benefits from emissions reduction is calculated as USD 99,935 per bus, and EIRR is 20%, which is higher than the social discount rate at 9%, which is the hurdle rate used by the ADB for its investment decisions.

Table 34: Economic Profitability of a BEB (12m)

Parameter	Value
Economic value of GHG reduction WTW per annum	2,659
Economic value for reduced criteria pollutants per annum	251
Total economic value of emissions reduction per annum	2,909
ENPV	99,935
EIRR	20%

4.3 Impact Assessment of the Proposed Bus Lines in Siem Reap City

4.3.1 Overview of the Operation Plan

Based on the information provided by the MPWT on the route plans and expected number of buses, the Siem Reap bus operation services are planned as per *Table 35* below.

Table 35: Siem Reap Bus Operation Plan

Parameter	Unit	Route 1	Route 2	Route 3	Total
Route length	km	13.66	20.32	15.05	49.03
Headway bus	minutes	10	14	10	
Average speed	km/h	19	19	19	
Stand time per side	minutes	6	6	6	
Cycle time	minutes	98	140	107	

Reserve buses	percentage	10%	10%	10%	
Fleet required at peak time	buses	10	10	10	30
Fleet including reserve units	buses	11	11	11	33
Passenger capacity 12m bus	passengers	80	80	80	
Annual distance driven per buses	km	90,000	90,000	90,000	

The next section assesses the environmental, financial, and economic impacts of introducing the BEB option in comparison to the diesel baseline.

4.3.2 Environmental Impacts

The GHG impact TTW (direct) of electric units is zero but their WTW impact reflects emissions related to electricity production. WTW also includes fossil fuels upstream-related emissions plus Black Carbon emissions.

Table 36 below shows the expected environmental impact of the e-bus fleet per annum and over the lifetime of the buses. In terms of local pollutants, the BEB option reduces $PM_{2.5}$ and NO_x emissions by 100%.

Table 36: Environmental Impact of BEB buses (unit: tons)

Emissions per Annum	Diesel		BEB		BEB reduction		
	Per line	3 lines	Per line	3 lines	%	Per annum	lifespan
CO2 emissions TTW	1,225	3,674	-	-	100%	3,674	58,785
CO2 emissions WTT incl. BC	356	1,069	901	2,703			
CO2 emissions WTW incl. BC	1,581	4,743	901	2,703	43%	2,040	32,645
PM2.5 emissions	0.1	0.3	-	-	100%	0.3	5
NOx emissions	7	21	-	-	100%	21	331

Noise emission levels of electric bus options are 50% below diesel buses.

Further GHG emission reductions can be achieved by producing at least part of required electricity through renewable sources such as solar PV systems installed on the rooftops of the bus depot or through building a new grid-connected solar power plant that would displace fossil fuel-based electricity from the grid. Further assessment would be needed to calculate the additional cost and benefits of sourcing electricity from renewable options based on the local situation.

4.3.2 Financial and Economic Impacts

The financial and economic impacts of introducing a BEB fleet for the proposed three lines in Siem Reap are assessed based on the concept of total cost of ownership (TCO). The same methodologies and parameters explained in the previous section (4.2.1) are applied for these assessments. The project life is assumed at 15 years considering the lifespan of the baseline diesel bus, and the residual value of batteries and infrastructure are added back in Year 15.

Table 37 below shows the summary of cost estimation for introducing e-bus systems in Siem Reap.

Table 37: Cost Estimation for introducing e-buses in Siem Reap (unit: thousand USD)

Item	Cost	Note
CAPEX_bus	11,224	33 e-buses (including reserve) * $340K per bus
CAPEX_ charging station	594	1 slow charger ($6,000) per bus, 0.2 rapid charger ($60,000) per bus
CAPEX_total	11,818	
CAPEX_battery replacement (Y9)	136	Battery lifespan = 8 years
OPEX_electricity cost	579	0.15USD/kwh*90,000km*1.3Kwh/km (per bus)
OPEX_maintenance cost	475	0.2 USD/km*90,000km*80% (per bus)
OPEX_total (annual)	1,054	

Table 38 below summarizes the main financial and economic results.

Table 38: Key Results of Financial and Economic Assessments (unit: USD thousand)

Item	Diesel	BEB
CAPEX bus (inc. 1 time battery replacement)	6,427	11,333
CAPEX bus infrastructure	0	594
Incremental total CAPEX		5,501
OPEX savings year p.a		1,011
Economic savings p.a		96
FNPV		1,991
ENPV		3,298
FIRR		17%
EIRR		20%
MAC per tCO_2 non-discounted/discounted (WTW)		-65/-321 USD

Table 38 above shows that the BEB option would require additional capital expenditures compared to diesel vehicles. However, introducing the BEB is financially and economically more attractive than acquiring a fleet of diesel vehicles over the lifespan, presenting the positive FNPV (approximately USD 2 million in total cost savings) and ENPV (approximately USD 3.3 million in net economic benefits). FIRR (17%) and EIRR (20%) are both above the financial and social hurdle rates (WACC at 10.3%, social discount rate at 9%), which means the TCO of the BEB option is lower than the diesel option, because OPEX savings are high. CO_2 Marginal Abatement Cost (MAC) for

the BEB option is negative which means that GHG emission reductions could be achieved at no cost.

BEB prices are decreasing quickly, especially in China, therefore estimates in this report should be considered conservative. Infrastructure costs are estimated based on global average prices of charging equipment. The estimates do not take into account the costs of connecting to the power grid and associated transformer stations. CAPEX does not include land costs needed for bus depots/terminals and infrastructure, which would be needed for both options. Further analysis will be needed in-situ to reflect local conditions around the charging locations (depots, terminals).

Operating electric vehicles such as BEBs leads to significant OPEX savings every year, due to the high price of diesel and the competitive electricity tariff in Cambodia. The GHG and pollutant reduction in physical terms is considered to be relatively robust. The monetary values of PM and NO_x reduction have a small influence, i.e., the major impact is related to the GHG emissions and their economic valuation.

Chapter 5: Smart Transport Systems (Optional)

5.1 Smart Transport System Options

Center system overview

Traffic information centers are needed to process and provide data collected from buses. Bus information is collected to the traffic information center through a wireless network, and after processing the bus information at the center, the information is transmitted to the bus information terminal through a wired or wireless communication network. The composition of the center system is as below.

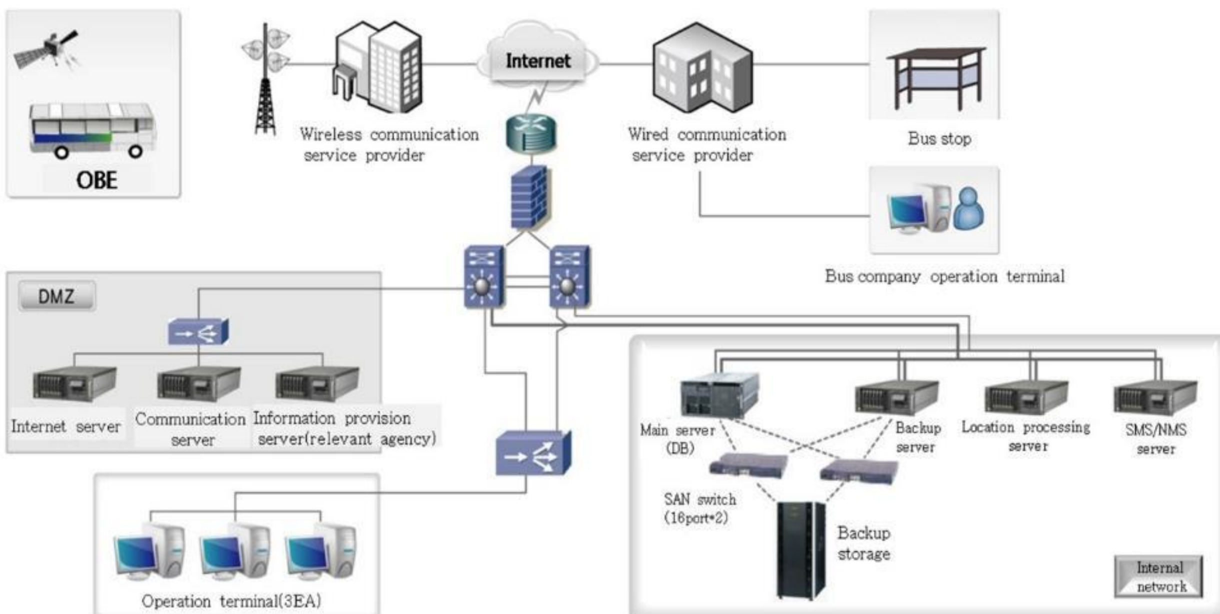


Figure 30: Center System Diagram

H/W of the traffic information center is divided into the control room equipment, server, and communication equipment. The control room equipment is related to bus driving monitoring, and the server and communication equipment are related to collecting, processing and providing traffic information. The main functions of subsystems constituting the traffic information center are detailed in *Table 39* below.

Table 39: Main Functions of H/W

System	Function
Main server (DB)	▪ Main functions of the traffic information center subsystem
Position processing	▪ Key processes such as data analysis/processing and algorithms ▪ Collecting real-time bus operation data processing

Communication	▪ Bus location information collection through 3G or GPRS communication ▪ Providing estimated bus arrival time through BIT and wired communication
Provide information	▪ Real-time monitoring of bus operation status, expected bus arrival time, accidents, violations, etc. ▪ Bus operation-related decision support through operation history statistics and traffic information processing
Internet information provision	▪ Introduce related services through the Internet website and provide information on operation status, optimal route, expected bus arrival time, route, and bus company information.
Backup/NMS	▪ Backup-Save backup data ▪ NMS-Network Management System
External storage	▪ External storage for large databases and backup data
SAN switch	▪ Connect primary server, backup server and external/backup storage via Fiber Channel (FC)
Operation terminal	▪ Center manager monitoring and control ▪ Route operation, route management, stop management, operation record management, etc.

Commercial S/W: The main center software includes S/W for existing H/W management and DB management, S/W connected with a firewall for network security, and an application S/W for system implementation. The main functions of the software features required for the center are as per *Table 40* below.

Table 40: Main Functions of Center Software

Item	Function
DBMS	▪ Integrated database storage
Backup S/W	▪ Central intensive management and various reporting functions
SMS/NMS	▪ Server/Network/Fault/Security/Management and Analysis ▪ Various Statistics Analysis and Report Generation
GIS S/W	▪ GIS Engine
Vaccine	▪ Virus blocking

Bus service management application: The Center BIMS controls/searches real-time bus operation information, predicted bus arrival information, accident information, and supports real-time monitoring so that operation information can be easily managed and provided.

Table 41: Main Functions of the Bus Service Management Application

Component		Function
Processing of collected information	Location information processing	▪ Accident and violation related data errors and decision adjustment
	Basic processing	▪ Real-time bus location, construction diagram, vehicle interval
	Processing applied	▪ Real-time bus location, construction diagram, vehicle interval

Bus operation management	Bus operation management	▪ Operation status monitoring, electronic map display, construction drawing
	Accident measurement	▪ Accident scenario, measurement by electronic map display
Accident management	Detection	▪ Receive accident signal from driver
	Recording	▪ Collected incident identification and result recording

Information provision system application: General information and real-time information are provided to travelers through BIT, and a web page is built in consideration of user convenience to provide services.

Table 42: Main Functions of the Information Provision System Application

Component		Function
Internet	Arrival time	▪ Bus Location, Expected Arrival Time
	Traffic condition	▪ Accident, Delay
	Shortest path	▪ Shortest Path with transfer
BIT	Route operation	▪ Operation route and related route information
	Bus stop operation	▪ Bus and Bus Stop Information by Bus stop
	Basic Information	▪ Route, Bus Stop, Fare, Transfer information

Bus operation data management application S/W: By providing parameter simulation to increase the accuracy of bus operation history statistical information, it provides functions such as generating and processing operation history and analyzing operation data.

Table 43: Main Functions of the Bus Operation Data Management Application

Content	Process	Function
Operation history information processing	Creation of driving history statistics information	▪ Daily/weekly/monthly/quarterly/yearly statistics data generation ▪ Generate statistics data by region/company/route/stop
	Traffic statistics information processing/analysis	▪ Creation of necessary information for bus operation management ▪ Operation performance, bus policy promotion effect index
Statistics by section	Speed by section	▪ Create speed for each section
	Speed by Bus stop	▪ Speed generation for each stop
Bus operation management	Search/print operation history data	▪ History data by section/route/stop
	Operation Statistics Data Search/Print	▪ Operation Statistics/Company Statistics Search ▪ Operation plan and performance comparison/inquiry

		▪ Passenger status, revenue analysis/inquiry
	Traffic analysis data inquiry/print	▪ Traffic analysis data inquiry ▪ Implementation of operation and construction diagram of the status and status of dispatch intervals ▪ Provision of necessary information for each stakeholder (center operator, bus company, etc.)

Bus route and stop management application SW: The relevant S/W is designed to facilitate the correction of route/stop information by the center operator.

Table 44: Main Functions of the Bus Route and Stop Management Application

Item	Process	Function
Route management	Route management	▪ Route inquiry/registration/modification/deletion, provision of flight schedule for each route, application of modified routes
Bus Stop Management	Bus Stop Management	New stop inquiry/registration/modification/deletion Modified stop registration
Others	Route bus basic information management	▪ Registration/modification/deletion of vehicle/company/fare information
	Electronic map management	▪ Status board and layer operation management
	Operation management update	▪ OBE route and bus stop history management update

Facility management system application SW: It enables remote updates of on-site facilities and equipment using wireless/wired communication networks and guarantees ease of maintenance by adding an integrated facility management function that can simultaneously manage central site facilities.

Table 45: Main Functions of the Facility Management System Application

Item	Process	Function
Basic information management	Basic information management	▪ Registration/modification/deletion/inquiry of basic facility information

Situation management	Collection of facility status data	▪ Real-time facility status information storage ▪ Notifying and storing the error history to the operator
	Facility status monitoring	▪ Message monitoring from BIT
Control management	Control management	▪ Real-time/period BIT On/Off control
	Remote update management	▪ BIT remote update management

5.1.1 Bus Information/Management System (BIS/BMS)

Bus Management System (BMS)

BMS Information Collection System: The BMS should monitor the location of each vehicle by collecting bus location data and operation data at regular intervals. It additionally performs the function of generating the average driving time per stop, the driving interval of the front and rear cars at the stop, and the expected arrival time. Processing and analysis of the collected BMS data is performed from the moment the raw data is collected by the in-vehicle terminal (OBE). When collecting data, it is necessary to establish a stable data collection system by setting an appropriate period in accordance with the components of each device, while maximizing availability in terms of information provision and analysis-management based on the collected data.

BMS Information Processing System: In general, the processing of traffic information is performed on the OBE or the main server of the traffic information center. In order to maintain the efficiency of the center system, it is desirable to process the collected raw data at the in-vehicle terminal (OBE) and transmit it to the center. The concept of processing in-bus information is based on securing the reliability of bus locations and operation data collected from vehicles. This maximizes the operational management effect by processing information based on a valid and systematic approach in traffic engineering by reflecting changes in traffic patterns. In addition, it aims to create accurate and integrated traffic indicators and promote public transportation by providing strategic traffic information through data processing and analysis.

BMS Communications: The GPS (Global Positioning System) is a method of measuring the location and time of objects on the earth by receiving navigation signals from 24 GPS satellites. The position measurement is obtained by measuring the distance to the satellite and using triangulation, and the time is based on the time sent from the GPS satellite. The measurement of the speed and the moving direction angle is calculated through the change of two-dimensional coordinates from the position value. In most countries, the method of calculating the location information of BMS follows the GPS method. To quickly transmit the collected data to the center after detecting the bus location, a communication method capable of transmitting between the vehicle, the in-vehicle terminal (OBE) and the center is required. The CDMA method operates through mobile communication base stations and exchanges and wired cables and radio waves. CDMA is an effective method for performing wireless communication by installing a mobile communication terminal or wireless modem in a vehicle. However, Pokhara (a city in India) can provide data service in connection with other networks in case of communication failure, and a

4G mobile communication LTE (Long Term Evolution) service is commercialized in most areas of Pokhara, so the wireless communication method for BMS is LTE.

Information Collecting System: The information collection method is divided into a fixed period (time period) method, an event method, and a hybrid method using a mixture of a fixed period method and an event method.

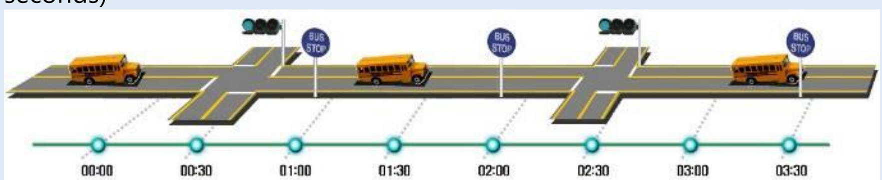
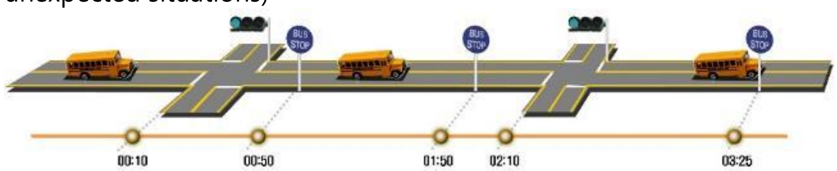
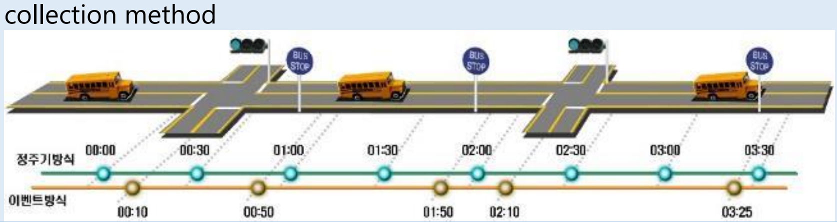
Content	Main Function
Regular Cycle Information Collection System	▪ A method of collecting information at random regular time intervals (collecting information collected every few seconds and sending it to the BIS center every few seconds) 
Event Information Collection System	• A method of collecting data only at the point of occurrence of some defined events (irregular events such as crossroads, arrivals and departures, and unexpected situations) 
Hybrid System (Fixed Cycle and Event Method Mixed)	• A method that complements the shortcomings of each data collection method by paralleling the periodic (time period) method and the event information collection method 

Figure 31: Three Types of Information Collection Methods

Source: Molit (2015)

Information Processing System: The estimated arrival time of the bus stop is calculated based on the travel time of each section, and the section travel time of the bus is estimated by applying a moving average method that utilizes the most recently encountered past information among the information collected as events to calculate the estimated arrival time. Also, based on the current time, the historical data used is differentially applied according to the route and section to predict the future section travel time. Estimated arrival time is updated every time the vehicle goes through a stop and intersection event, and the number of stops is updated each time the vehicle goes through a stop event. "Arrival in a moment" information is provided when a departure event occurs at an upstream stop.

OBE: An important element at the core of the bus management system, is the function of collecting bus information. Various information on the bus collected from the bus terminal (OBE) mounted on the bus is collected and integrated into the bus management system S/W to build a usable DB. The vehicle terminal (OBE) is the location of the bus and provides basic bus location information such as time, running speed, running distance, and bus status to the center. In addition, it detects and transmits the operation history information such as the arrival time of the stop, the current bus location, and the intersection passage time to the center.

The OBE UI is largely composed of a basic driving information screen including the front and rear vehicle intervals for the driver, and a time and distance interval screen including the driving time, route map, and remaining distance.

An integrated terminal system of the Server-Console concept has recently been developed and commercialized by integrating and controlling various systems in the vehicle such as in-vehicle terminal (OBE), destination information indicator, in-vehicle CCTV, in-vehicle passenger information terminal, and toll collection.

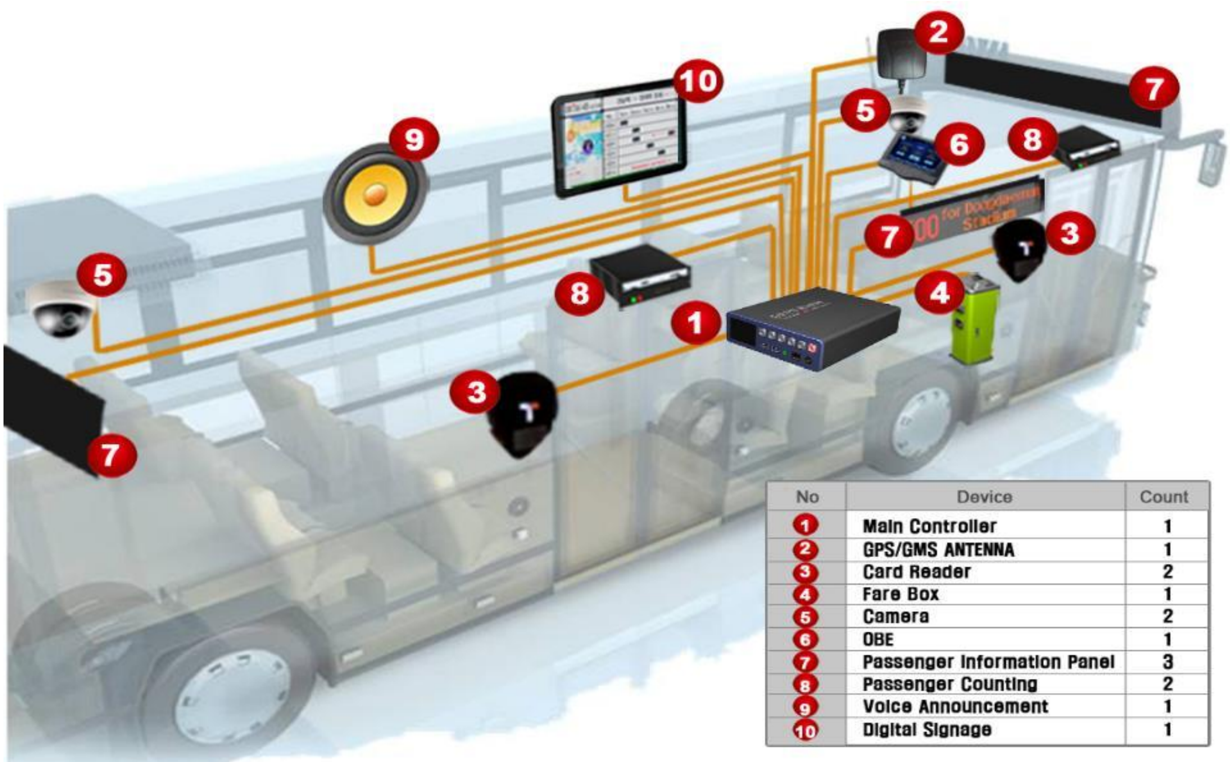


Figure 32: Integrated Terminal of the Server-Console Concept

5.1.2 Advanced Traffic Management System (ATMS)

An Advanced Traffic Management System (ATMS) provides users with traffic information in real time and supports managers to perform traffic management duties and establish necessary policies by collecting and providing traffic data on urban arterial roads. ATMS also aims at achieving optimized traffic management of arterial roads and maximizing the utilization rate of roads within cities through traffic system management, intersection monitoring and incident management through connection with relevant agencies.

ATMS establishes a system to collect, provide and manage real-time traffic information from main arterial roads (expressway or national highway) within and between communities across Siem Reap.

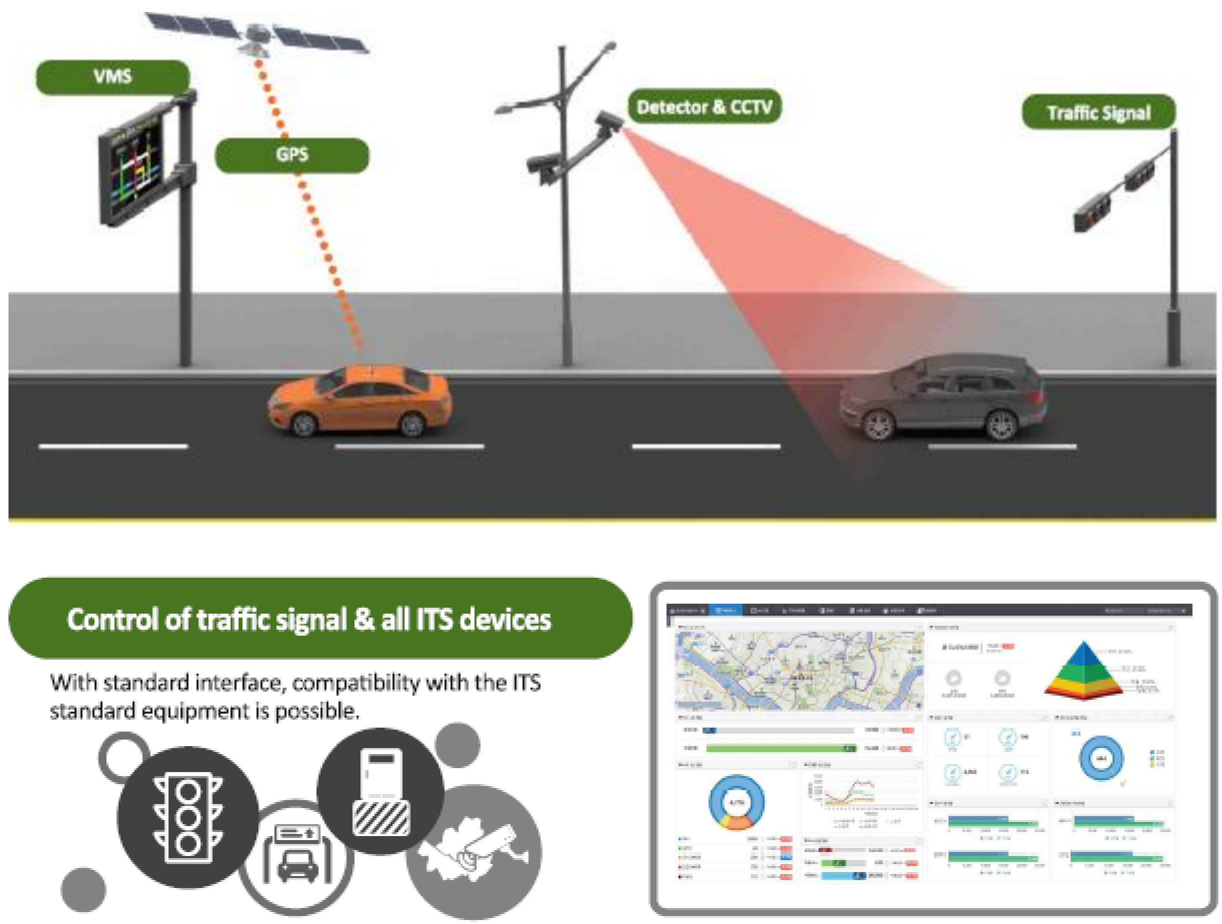


Figure 33: The Concept of an Advanced Traffic Management System

Source: Seoul TOPIS Platform

An urban traffic management system consists of a traffic flow control service that controls traffic lanes and vehicle access, an incident management system that controls traffic accidents and incidents, and basic traffic information provision service for citizens.

Table 46: Main Functions of an Advanced Traffic Management System

Function	Description
Traffic network data management	Geometric structure of roads, road facility data update and management.
Vehicle detection	Detection of vehicle (traffic flow) status (characteristics).
Vehicle detection data processing	Data received from individual detectors are processed, integrated and converted into data of relevant road sections.
Vehicle identification data management	Collection vehicle identification and information management.
Vehicle location identification	Identification of vehicle location.
Processing vehicle location data	Vehicle operation data are collected and produced by processing vehicle location data.
Incident detection	The occurrence of incidents is detected by analyzing detection data and vehicle operation data.
Incident identification	The occurrence of an incident that has been detected or reported. The operator identifies an incident by checking video data and enters data necessary for the analysis of such incidents.
Incident analysis	The analysis of the seriousness and time duration of an incident.
Incident progress monitoring	Monitoring of the progress and handling status of incidents. The operator monitors the progress of incidents by checking video data.
Countermeasure determination	The determination of measures to deal with an incident and minimize delays caused by such incidents.
Traffic flow control	The control of the access of traffic flow and traffic lanes to minimize the effects of an incident.
Processing incidents	The dispatch of persons who handle an incident.
Display of incident information	The display/provision of incident information for drivers and travelers in order to encourage their safe driving and detouring of the location where an incident occurs.
Receiving incident reports	Receiving traffic situation information from informants or information sources.
Monitoring traffic situation	Recording video images and monitoring of traffic situation. The operator monitors traffic flow by checking video images.
Road traffic data collection and analysis	The comprehensive collection and analysis of data collected from various information sources.
Production of traffic flow information	The production of traffic information to be displayed by media including VMS and the Internet according to information provision strategies.

Display of traffic flow information	The provision of traffic flow information and video images through information provision media.
Lane control strategy determination	The determination of the lane control strategies of uninterrupted roads.
Display of lane control signal	The display of lane control signals of uninterrupted roads.
Entrance control strategy determination	The determination of strategies to control access roads to uninterrupted roads

5.1.3 Illegal Parking Enforcement System/Parking Management System

Illegal Parking Enforcement System

Illegal parking can lead to reduced traffic speeds, congestion, changes in modal choice, a decline in respect for the law, and even to accidents. Its potential impact is of such magnitude that it is now widely recognized that policies aimed at its control should be incorporated into any sensible transport plan. An illegal parking enforcement system detects a vehicle without the manual control of the user via an automatized system. Unmanned auto detection, even on the spot, resolves frequent complaints in the area of detection, can apply scan detection and video clip detection, overcome limits of human tracking on regular illegal parking zones, and saves time and cost. Various models (Fixed type - three auto cameras, one semi-auto camera, auto/semi-auto speed dome type) can be interlocked with other systems. Setting exact coordinates with the function of learning coordinates helps maximize detection efficiency.

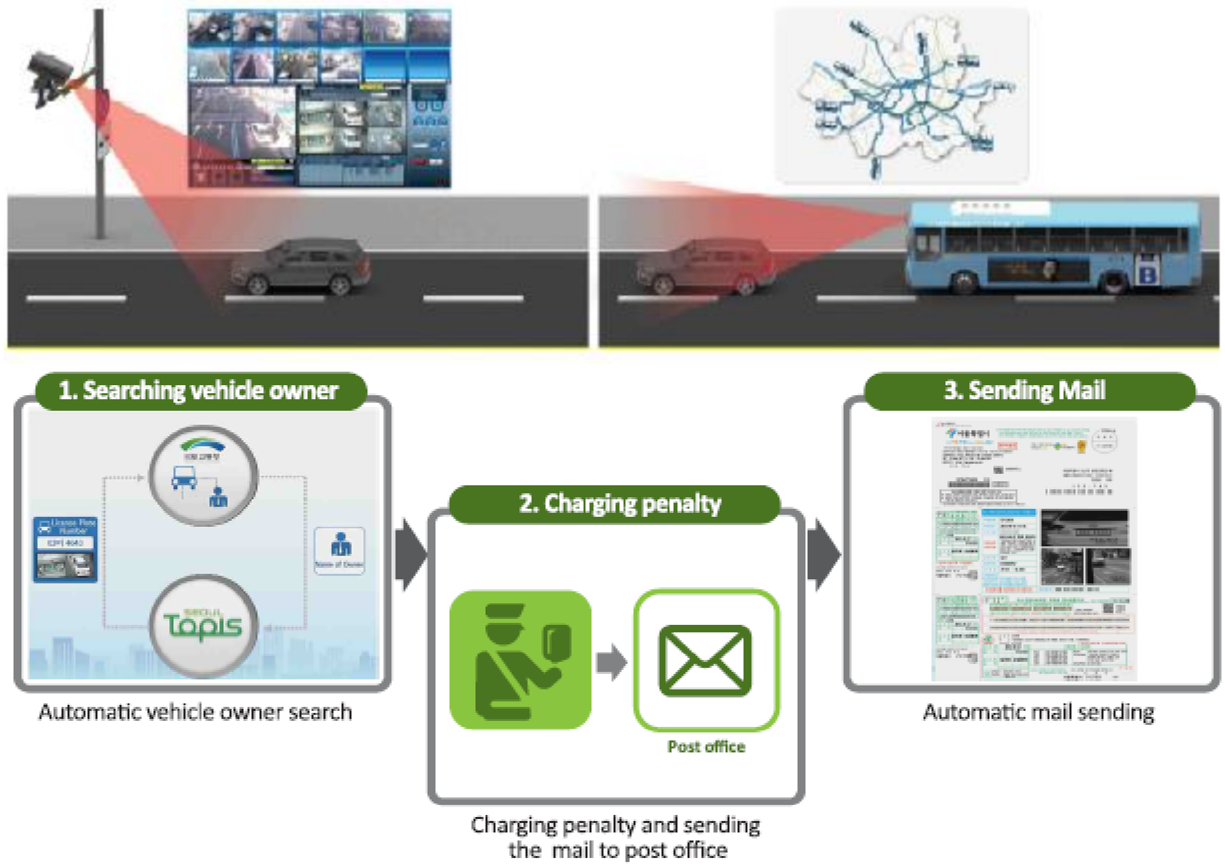


Figure 34: The Concept of an Illegal Parking Enforcement System

Source: Seoul TOPIS Platform

The logical architecture of an Illegal Parking Enforcement System (IPES) defines the data flow and functions of the system and describes the details of the functions. It can be classified into a crackdown through the installation of the Illegal Parking Enforcement System and a crackdown through the vehicle filming device embedded on the bus. The IPES is classified into the automatic crackdown and the semi-automatic crackdown operated by a crackdown monitoring officer.

Parking Management System

A Parking System Management (PMS) is a worthwhile tool for consideration given the lack of parking spaces in Siem Reap. The parking of vehicles on the side of the road can be irksome and also deters traffic. Enforcing the parking of vehicles in appropriate areas can be useful to everybody and help to deal with the assets in a legitimate manner.

All-around structured and productively created parking software will help parking authorities. It is product that essentially assists management individuals in dealing with numerous undertakings one after another, which would have been difficult to oversee at once without the establishment of the PMS. Issues related to parking management of vehicles and the services given by service authorities likewise forestalls effective planning, implementation, and acceptance of public transportation.

A PMS works on a modular basis producing the exchange charges for a vehicle per the parked location. Furthermore, it generates data that helps find the space in the assigned territory swiftly and precisely and provides a more significant level of organization for the legitimate services and security. The system thinks of a computerized parking module that helps by observing the vehicle through the system and assists the assigned trained staff in managing the proper security levels in the parking zone.

With the use of PMS's, authorities can predict problems that might occur and reduce the chances of damage and/or destruction of property. Such a system provides for greater simplicity in managing the task than, if any, earlier work without it. As a result, public authorities can creatively consider the optimum solutions for issues identified with urban center parking.

Parking Management Systems Advantages:

- Snappy and simple management of services.
- Control over all sections while leaving focus on the system with a solitary administrator.
- Traffic estimation and computation of vehicle installment and charges.
- Robotized System for controlling and management of parking areas.

Subsequently, as well as providing for better parking management facilities, a parking management system can also help generate an additional source of income for the parking authority.

5.2 Deployment Plan for ITS

The transport satisfaction survey of Siem Reap citizens identified that smart transport systems would be a useful option for improving the transport infrastructure. The major transport problems identified by citizens in Siem Reap were traffic congestion, lack of traffic information, and lack of parking spaces. While a proper technical and financial feasibility assessment of ITS falls beyond the scope of this study, further analysis on this topic is recommended. The provision of traffic information and alleviation of traffic congestion can be addressed with the introduction of the traffic signal system and the introduction of ATMS. Traffic congestion in Siem Reap can be alleviated by providing a bypass route through ATMS and interlocking traffic signals. PMES and PMS can help to solve the parking problem felt by Siem Reap citizens by reducing illegal parking and efficiently securing parking spaces.

Problems arising in the transport sector are the absence/accuracy of bus information, irregular bus arrival times, and bus facilities and services. By providing bus information to citizens through BIS, user satisfaction can be improved, and common transportation demand can be increased. Degraded bus facilities can be solved by improving bus shelters and introducing e-buses.

Table 47: Transport Issues and Solutions

Transportation Issues	Score	Rank	Needed System

Frequent congestion at intersections	658	1	ATMS
Frequent congestion on roadways	490	2	ATMS
Lack of parking spaces and facilities	396	3	PMES/PMS
Non-recurrent congestion due to accidents or road construction	266	4	ATMS
Lack of traffic information or inaccuracy of the information	173	5	ATMS

Table 48: Transportation Issues and Solutions

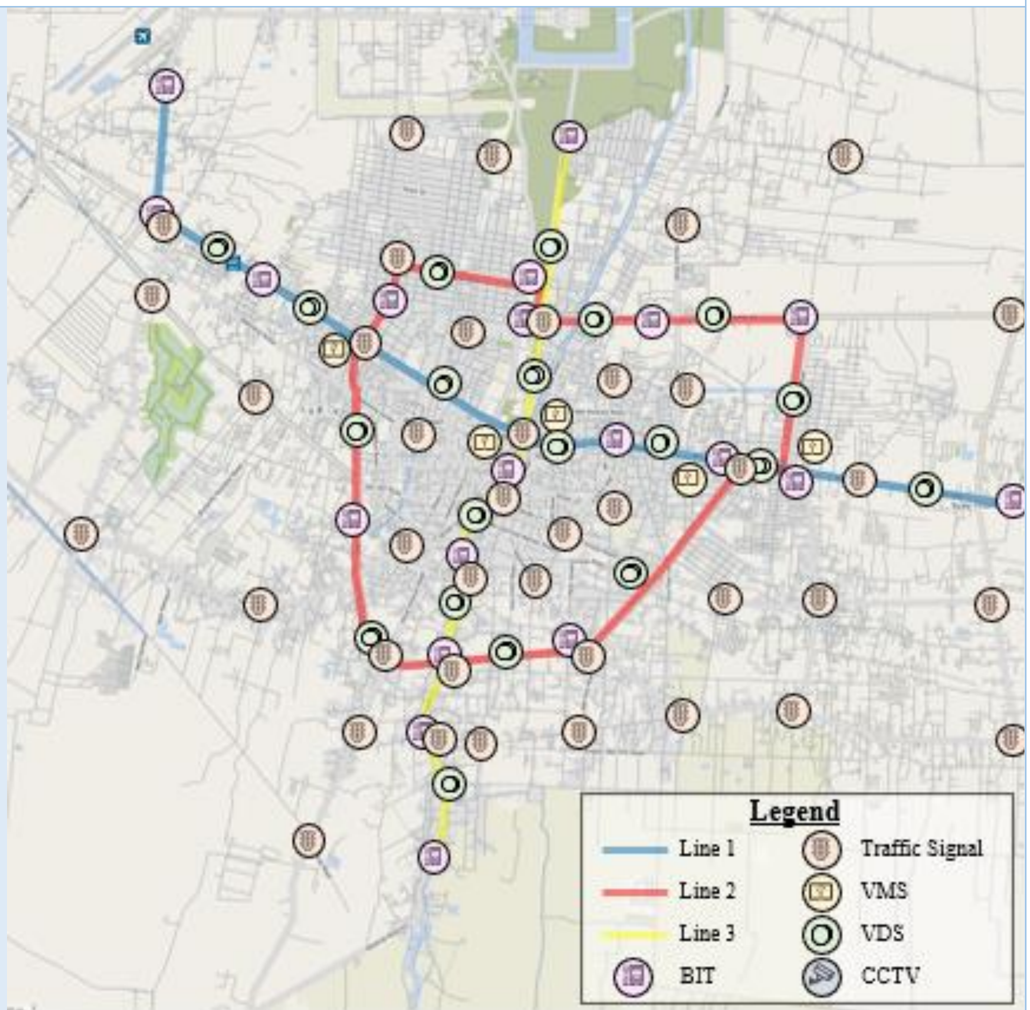
Transportation Issues	Score	Rank	Needed System
Lack of information on transportation services	111	1	BIS
Increase in transfer and travel time due to insufficient bus routes	94	2	BMS
Few and irregular bus frequency	91	3	BMS
Inaccurate transportation services information	88	4	BIS
Poor facilities of bus vehicles and lack of services	82	5	e-bus

In consideration of the current transport conditions, it is suggested to introduce ITS services step--by-step as follows:

- **1st phase**: Advanced Traffic Management System (ATMS), Bus Information System (BIS), Bus Management System (BMS)
- **2nd phase**: Illegal Parking Enforcement System (IPES), Parking Management System (PMS)

Table 49: System Deployment Plan in Phase I of the Project

Component		Nos	Unit	Unit cost	Cost (USD)
Center	H/W	1	set	776,000	700,000
	S/W	1	set	769,000	700,000
	N/W	1	set	182,000	180,000
	Interior	1	set	296,000	300,000
	Sub-total				1,880,000
BIS/BMS	BIT	20	ea	15,000	300,000
	OBE	33	ea	5,000	165,000
		Sub-total			465,000
ATMS	Traffic Signal	40	ea	35,000	1,400,000
	VMS	5	ea	20,000	100,000
	VDS	10	ea	15,000	150,000
	CCTV	5	ea	15,000	75,000

	Sub-total	1,725,000
	Grand total	4,07,000
Plan		

Chapter 6: Low-Carbon Transport Implementation Strategy

6.1. Enabling Environment for Introducing the E-bus System

Introducing e-buses can solve critical urban issues such as traffic congestion, GHG emissions, and air pollution caused by increased use of fossil fuel-based private vehicles in the city. As it would be the first public bus system in the city and the first formal proposal for introducing an e-bus solution in Cambodia, it is critical to assess the enabling environment for introducing e-buses and subsequent potential challenges. The World Bank (2019) defined the main factors that influence the enabling environment for clean buses as per *Figure 35* below. The framework was used by the World Bank to analyze and evaluate five cities in Latin America, which also is useful to assess the readiness of introducing e-bus systems in Siem Reap.

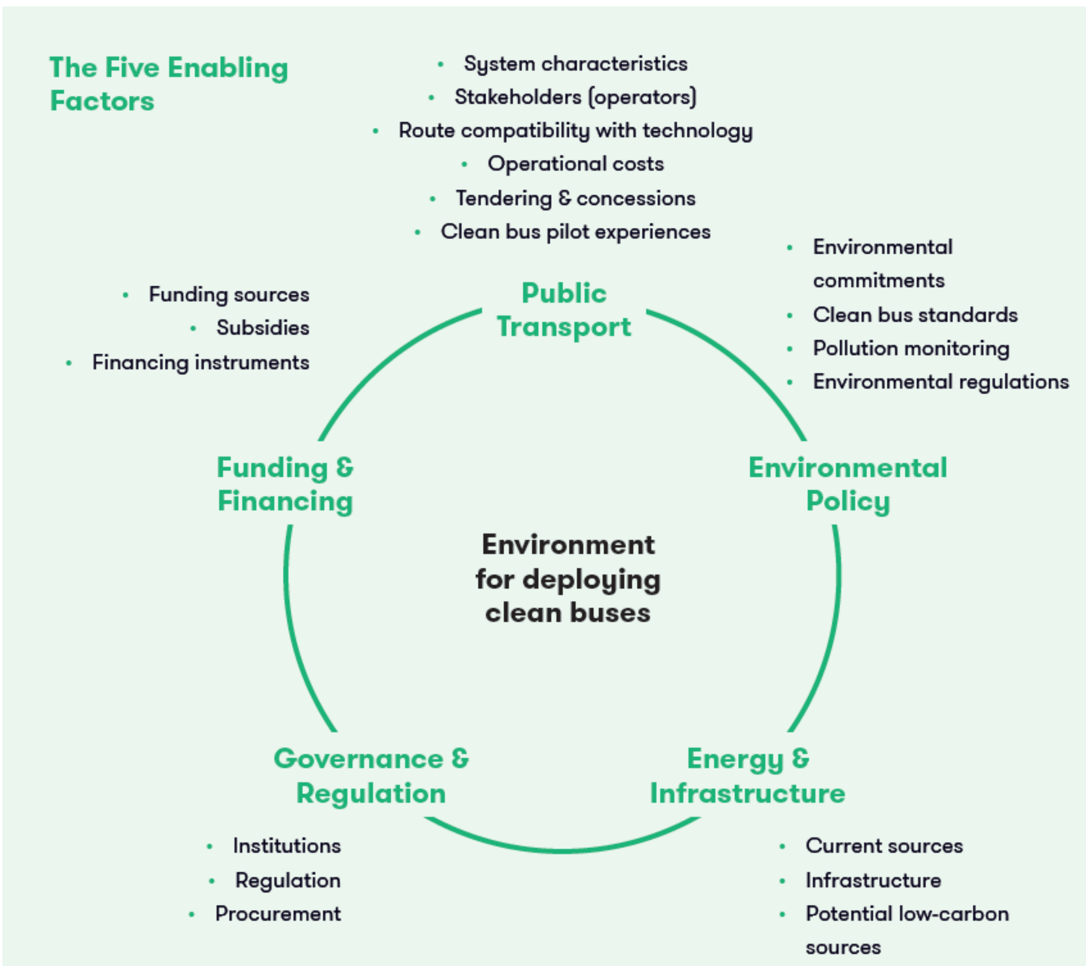


Figure 35: Main Factors Influencing the Enabling Environment for Clean Buses

Source: The World Bank, 2019.

Table 50 below presents a quick assessment of the enabling environment of Siem Reap City based on the suggested factors.

Table 50: Quick Assessment of Enabling Environment of Siem Reap City

Enabling Factors	Quick Assessment of Siem Reap City
Public Transport	• Efficient public transport system and clean bus pilot experiences are important enabling factors, which are lacking in Siem Reap (there is no public transport system in the city). • Bus emissions standards should be established to support the introduction of clean technology. • Route compatibility with the BEB technology should be examined in-depth in the F/S stage.
Environmental Policy	• Environmental commitments can be a strong driver for deploying e-mobility and introducing e-buses. • Cambodia and Siem Reap have high-level strategies and plans for green growth and smart/sustainable cities, but no specific emission targets in the transport sector in its revised NDC. This may be a disadvantage in attracting international climate and/or development finance in the sector. • Regulations for battery management and disposal should be introduced to prevent contamination of soil and water from used battery waste *(further discussed in 6.2)*
Energy and Infrastructure	• Stable supply of and easy access to electricity or low-carbon energy sources are a pre-requisite *(further discussed in 6.2)*. • Mitigation impact of e-buses will depend on the "greenness" of the grid, e.g., degree of electricity generated from low-carbon sources. • Grid carbon factor of Cambodia (0.7kgCO2e/kWh) is above the median value (0.66) in Asia[38], which means the grid is relatively less green in the region.
Governance and Regulation	• Key success factors include solid institutional arrangement for the introduction, operation, and supervision of e-bus systems, as well as effective coordination among diverse stakeholders including national ministries, provincial/local governments, transport authority, and operators *(discussed further in 6.4)*. For example, a lack of institutional coordination was identified as the main barrier in most cities in Latin America, and fragmented governmental authorities have failed to integrate transport system planning and policies.[39] • Market competition will lead to lower costs and higher quality, so it is important to promote competition in the procurement process.

[38] ADB, 2019.

[39] The World Bank, 2019.

	• Power distributer (EDC) can be a critical partner for any e-bus project in installing charging stations and potentially by offering favorable electricity tariffs for public service operations.
Funding and Financing	*(Discussed in 6.3)*

6.2 Potential Risks and Mitigation Strategies

For large scale investment projects, it is important to identify associated risks that can negatively affect the project implementation and prepare mitigation/management plans. *Table 51* below describes potential risks and possible actions to be taken to mitigate those risks. Rigorous assessment of potential risks should be conducted, and risk management plans should be developed in consultation with diverse stakeholders in the project design stage.

Table 51: Potential Risks and Mitigation Strategies

Major Risks	Description	Risk Mitigation Strategies
Negative impact on local jobs in the transport sector (mainly tuk-tuk drivers)	• Tuk-tuks are a popular means of transport for tourists in the city. Airport tuk-tuks are also available as part of the Tourist Transportation Association (TTA). • Introducing public bus services is likely to reduce demand for tuk-tuks, negatively affecting the revenue of tuk-tuk drivers.	• As suggested by local government authorities, stakeholder consultations should be conducted to share potential project impacts on the local economy including local jobs and to discuss how to minimize negative impacts and maximize benefits to the local community.[40] Consultations had been planned as part of the current study but could not go ahead due to COVID-19 restrictions. • The government can consider introducing e-bus lines in a phased approach and prioritize a bus line which has the least impact to tuk-tuk drivers. For example, Line 1 which connects Siem Reap International Airport to the city center can have relatively lower impact as major modes of transport for foreign tourists from the airport to the city or tourist destinations are identified as private buses and family vans[41], while improving tourist access to the city center. Also, tuk-tuks can play a complementary role to e-buses providing a last mile connectivity solution. • Introducing an e-bus service will create green jobs for local people including drivers, operational/managerial staff, technicians, etc. In order to localize the

[40] Summary of Focus Group Discussions/questions organized by DUPT and GGGI (February 2021)

[41] Summary of Focus Group Discussions/questions organized by DUPT and GGGI (February 2021)

		newly created green jobs, training and capacity building activities should be offered to local people. • Economic and environmental benefits of the project should be shared and widely promoted to mitigate potential resistance.
Lack of institutional and technical capacity for e-bus operation.	Siem Reap city has neither a public bus service nor a transit authority that has experience and capacity in operating public bus systems. Lack of implementing entity/focal organization is a key risk as the project involves not only sustainable bus operations but also new technologies which require technical capacity and well-designed coordination with multiple stakeholders.[42]	• TA activities would be needed to build institutional capacity of the relevant authorities to set up a dedicated transit authority/unit and operationalize the public bus services. • Capacity building activities are essential to train the e-bus/charging station operators, drivers, technicians for repair and maintenance, etc. For the first few months, it would be critical to have technical support from international experts/technicians on-site who can help stabilize the operation.
Demand risk	Passenger demand for the suggested bus lines has not been technically assessed. Lack of passenger demand will lead to increasing operational deficit from bus services, causing negative fiscal impact on the competent authority and ultimately the national government.	• Technical assessment on passenger demand including stakeholder consultations as well as public hearings should be conducted in order to share the proposed bus lines and get feedback and suggestion from citizens and potential users. • Prioritization and phased introduction of the bus routes based on demand assessment can be an option. • Promotion and communication activities in cooperation with relevant authorities such as the Ministry of Tourism and APSARA will be useful to boost passenger demand.
Environmental impact of used battery waste	• The lithium-ion type of battery needs to be replaced every 8-10 years and recycle and/or disposal of used batteries could be an issue in the environmental perspective. Lithium	The primary focus should be on prolonging the life of the batteries for their original purpose and identifying options for secondary usages as following: • Prepare a comprehensive battery recycle/disposal plan potentially in collaboration with battery recycling firms and/or battery suppliers.

[42] Siem Reap introduced 50 e-buses sponsored by a Chinese company in 2010 provided for serving tourists in the Angkor area. However, only three units are currently operational only for administrative use. Key difficulties identified in this experience include lack of technical knowledge (no technical assistance provided for operation); poor quality of the vehicles combined with weak capacity for repair and maintenance; no public support (Summary of Focus Group Discussions/questions organized by DUPT and GGGI, February 2021).

	batteries are complex and expensive to recycle, requiring chemical and metallurgical complex processes. • Used batteries from EVs can be recycled to extract raw materials needed for new battery production or reused for other purpose such as energy storage. However, it is unlikely that Cambodia will have the technical capacity or necessary battery waste volumes to establish comprehensive battery recycling operations in the medium term.	• Select a vendor with high battery specifications and a comprehensive and lengthy warranty. As the batteries are expected to be changed once during the life of the buses, investigate a take-back or sell-back scheme with the provider. • Investigate secondary markets within Cambodia and have a plan in place within 5 years of battery operation. • Develop a standard operating procedure (SOP) for battery maintenance in line with battery specification and provide comprehensive training to the maintenance crew. • Develop an SOP and provide comprehensive training to drivers, with the aim to reduce battery stress. The SOP should include optimal driving speed, avoiding unstable driving styles with greater speed variation or acceleration, when to recharge, optimal charge times, swapping buses on the most demanding routes, etc.
Land available for e-bus depot/terminal	The project would require land available for a bus terminal and depot in place for parking, charging and maintenance. This is currently not available/planned in the city.[43]	• Real estate should be secured in proper locations before procuring buses and chargers in the project preparation stage. • Important conditions/issues to consider in determining the location would include access to the grid, potential social and environmental impacts including resettlement as well as land cost.
Impact on the grid	• Access to cheap and reliable electricity is key for sustainable service operation. • Introducing e-buses will increase electricity demand particularly for the hours for charging, which may affect grid stability.	• It is important to engage the local EDC from the early stage, ideally as a partner to the project. The local utility can "have the requisite knowledge of the power requirements" and offer "reasonable fixed-price energy to the operators".[44] • If the project can potentially affect grid stability, it should be assessed if additional investment in the grid is required.

[43] Focus Group Discussions/questions organized by DUPT and GGGI (February 2021)
[44] IFC, 2020a.

6.3 Financing Strategies

The most common method for financing e-buses is self-financing combined with government grants[45], as is the case for conventional public bus procurement. In Europe and the US, for example, grants from regional, national, and federal levels are provided to cover part of e-bus purchase costs, while funding from the bus operator and the local/state government fills the financing gap. This would not be feasible option for many developing countries, particularly in consideration of the large upfront cost of e-buses. To alleviate this issue, alternative financing models are being developed which reflects the requisite cash flow from e-bus investment and operation.

6.3.1 Leasing Scheme

E-bus options have higher initial CAPEX but lower OPEX. A potential financing option, therefore, is to lease buses or the batteries only. Leasing can be an effective way to reduce the substantial upfront cost for purchasing e-buses, thus alleviating the fiscal burden of the public authority or bus operator, while enabling the authority to use OPEX savings to make lease payments. The lease model can also be structured to mitigate technology risks associated with battery price, performance, and replacement on the part of the bus operator/lessee and to enable the e-bus fleet to be the most cost-effective possible.[46] In the US, federal grants are provided for e-bus purchase but they are not sufficient enough to cover more expensive e-bus acquisition cost, so a battery lease scheme has been introduced to procure batteries. Lease costs for batteries are paid with the operational savings of the e-bus fleet.[47]

Introducing the lease option would require a shift from a conventional bus procurement decision method from purely looking at CAPEX towards a comparison of the TCO. Most cities still make procurement decisions based on the lowest upfront cost, thereby favoring diesel bus options more frequently. Procurement should be shifted to a focus on the TCO or lifecycle costs, so e-buses can compete with conventional diesel buses on a level playing field.

6.3.2 Public Sector Financing for Infrastructure

The government budget is the primary source for transport financing in Cambodia. Public sector investment in the form of equity, subsidies/grants, or in-kind contribution is highly recommended to present a strong government initiative for the proposed investment project as sponsor and to attract co-financing from MDBs, donors, and private partners.

Alternatively, state-owned enterprises in the relevant sector, such as EDC, can be also considered as an equity contributor as it will directly benefit from the suggested project and overall electrification of vehicles in the country. In particular, investment costs in charging infrastructure

[45] BNEF, 2018.
[46] BNEF, 2018.
[47] IFC, 2020b.

can be financed and managed through EDC, as is the case in many cities worldwide. The electricity company thereafter recovers this investment through charging a service fee to the transport operator through general sales of electricity i.e., the investment is treated just like an investment in the grid. This will result in a very marginal cost per electricity user and can be justified due to the significant external benefits of electrified urban transport from which all stakeholders can profit.

6.3.3 Climate Finance

Concessional climate finance to (partially) cover incremental CAPEX or charging infrastructure can also be a potential option. This could potentially be grant financed. However, full grant finance to cover the incremental CAPEX e.g., through the Green Climate Fund, might not be a realistic option considering the nature of the project given its primary focus is to generate revenue. GCF has financed only one transport project to date for introducing a bus rapid transit (BRT) system in Karachi, Pakistan. The project included a biomethane hybrid bus fleet, a dedicated biogas plant to cover the fuel demand, and last mile connectivity via bikes and e-pedicabs. GCF provided USD 37.2 million in loans and USD 11.8 million in grants, co-financed by the ADB and the provincial government. More recently, the GCF tends to only provide loans for mitigation projects, with relatively small amount of grants for TA and capacity building activities, where deemed necessary. However, partial grant finance may be positively considered due to the LDC status of Cambodia and its needs for international financial support to achieve conditional Nationally Determined Contribution (NDC).

Although the transport sector is among the largest contributors to GHG emissions, it has not been a major area for climate finance. It is reported that less than 2% of climate finance projects have been focused on low-carbon transportation solutions. The World Bank Clean Technology Fund (CTF provided 16% of its fund to low-carbon transport projects, and the Global Environment Facility (GEF) less than 10% of its climate mitigation related funds to transport.[48] The NAMA Facility has six transport projects in the preparation and implementation stage including financial and policy support for mass public transit systems and non-motorized transport. However, since Cambodia does not have explicit transport targets in its 2020 NDC under the Paris Agreement, NAMA may not consider it eligible.

6.3.4 MDB and Donor Funding[49]

Sustainable transport is one of the key areas for MDB engagement and support. It is reported that the eight largest MDBs offered USD 4.7 billion for climate change mitigation in the transport

[48] SLoCaT, 2018.
[49] SLoCaT, 2018.

sector in 2016, which accounted for 22.8% of total mitigation finance. Relatively, ODA funding to the transport sector has been small, representing only about 2.5% of total transport sector investment in the Asia-Pacific region in 2015.

Considering the size of the project, it may be more effective to attract bilateral ODA. Among bilateral donors, China, Japan, and the Republic of Korea were the most active in terms of climate mitigation expenditure in 2018 (See *Table 52* below).

Table 52: Climate Change Expenditure by Development Partners for Cambodia

		2016	2017	2018	% share 2018	Adaptation 2018	Mitigation 2018
1	ADB	33.9	43.8	45.9	41%	45.4	0.5
2	China	30.5	36.4	21.7	19%	13.7	2.4
3	Japan	4.6	11.7	13.8	12%	7.0	0.8
4	IFAD	4.4	6.2	5.7	5%	5.3	0.4
5	UNDP	0.9	2.1	4.4	4%	4.3	0.0
6	Republic of Korea	2.9	5.1	3.9	3%	1.2	0.4
7	Australia	6.5	4.8	3.6	3%	1.8	0.1
8	EU/EC	4.4	3.8	2.8	3%	2.7	0.0
9	USA	4.6	4.0	2.5	2%	1.7	0.2
10	Sweden	2.0	1.0	2.4	2%	1.0	0.1
11	Others*	7.3	6.1	6.3	6%	4.9	0.1
	Total	102	125	113	100%	89	5

* France, Germany, World Bank, FAP, UNIDO

Source: Ministry of Economy and Finance (2020, June)

JICA has been working with the Siem Reap Provincial Administration on sustainable urban development. It is currently developing a Siem Reap Smart City Plan in cooperation with the Siem Reap authorities, building on its previous studies for an Integrated City Master Plan.[50] Korea is also a potential donor, as Cambodia is one of its key partners and ODA recipients, particularly under its New Southern Policy and strengthened partnership with ASEAN countries. For example, the Korea Energy Agency has worked with the Cambodian government (Ministry of Mines and Energy) for a solar-charged e-bike project since 2019 and set up solar PV and charging stations in Siem Reap for demonstration. The Korea International Cooperation Agency (KOICA), Korea's ODA (grant) agency, has provided co-financing for a preliminary assessment for promoting green

[50] Study on an Integrated Master Plan for Sustainable Development of Siem Reap / Angkor Town in the Kingdom of Cambodia (2006); Follow-up Study on Integrated Master Plan for Sustainable Development of Siem Reap City in the Kingdom of Cambodia (2010)

mobility in Cambodia and can engage in the project providing grants for program design, TA and initial investment.

6.3.5 Private Sector Financing

Private sector participation can be considered for the e-bus operations as a concessionaire, however, public support would be necessary to build charging infrastructure and even to finance part of the e-bus acquisition costs, as few public transport systems recover their CAPEX through operational revenues alone. This is because bus fares must be affordable and socially acceptable for the general public, and operators cannot normally increase the fares as they would wish. In some global cases, operational subsidies are provided to operators when operational revenue cannot cover OPEX due to regulated bus fares.

6.4 Key Stakeholders and Implementation Arrangements

Given there is no current public bus service in Siem Reap City, it is important to identify key public and private agencies for procuring and operating e-bus systems and to design an implementation structure. As highlighted in the previous sections (6.1, 6.2), solid institutional arrangements as well as effective coordination among stakeholders is a key foundation for the successful introduction and operation of any e-bus system. *Table 53* below summarizes the expected roles and responsibilities of key ministries and local public entities which are associated with the proposed e-bus services.

In Phnom Penh, the Autonomous City Bus Transportation Authority is in charge of the Phnom Penh City Bus service, a municipal public transport system which consists of 17 bus lines. In Siem Reap, the municipal government would be in charge of procuring e-buses and necessary infrastructure, and then operating public bus systems as is the case in Phnom Penh. A dedicated municipal public transit authority would be needed to manage any new bus systems. Strong support from and coordination with MPWT and relevant central public entities such as the Ministry of Mines and Energy, EAC/EDC, Institute of Standard of Cambodia are also critical as the project would be the first introduction of e-bus systems and infrastructure in Cambodia. The Ministry of Economy and Finance should be also involved in the introduction of new regulations, standards, incentives, and support. Partnerships with the Ministry of Tourism and APSARA (Authority for the Protection of the Site and Management of the Region of Angkor) are important for effective e-bus operation as the service is designed to serve tourists as well as citizens connecting the international airport, city center, and major tourist destinations. In addition, donors, international organizations, and multilateral financial institutions/funds can be key partners who can provide technical assistance, capacity building and/or financing for procurement, operation and management. For example, JICA has been working with the Phnom Penh Capital Administration to enhance the operation and management of the city bus systems since 2017 and provided 80 buses to the city bus authority.[51] Expected roles and responsibilities of key local stakeholders are as follows.[52]

Table 53: Expected Roles and Responsibilities of Key Local Stakeholders

Name of Entity	Major Function	Expected Roles in Relation to Proposed E-bus Project
Department of Urban Public Transport (DUPT), Ministry of Public Works and Transport (MPWT)	• To prepare plans, policies, laws and legislation for the management of the public transport means; • To collect, compile, analyze, and manage the statistics and data on transport; • To manage the public transport; • To cooperate with the national and international institutions for the development of the transport sector	• To propose and prepare laws and regulations related to the introduction and operation of sustainable e-bus systems; • To prepare policy and strategy related to e-bus system operations and management; • To encourage and incentivize e-bus users and operators; • To lead stakeholder consultations to define and prioritize routes for public e-bus services; • To facilitate and negotiate with the relevant institutions and stakeholders; • To provide technical guidance and standards for e-bus operations; • To conduct monitoring and evaluation of e-bus operations.
Siem Reap Department of Public Works and Transport	• To implement and coordinate activities of MPWT related to public works and transportation at local level such as road and bridge construction, road safety, and vehicle registration, etc.	• To facilitate and support the work of MPWT described above; • To integrate the e-bus system into infrastructure development plans of Siem Reap province; • To manage operations of e-bus systems; • To identify needs for expansion of e-bus systems in Siem Reap province

[51] https://www.phnompenhpost.com/business/improving-public-bus-operations-phnom-penh
[52] Collected from Focus Group Discussions/questions organized by DUPT and GGGI (February 2021)

Siem Reap Province/ Siem Reap City	• To prepare and submit to the council for consideration and approval of three-year investment program and budget plan, five-year development plan and medium-term expenditure plan, and annual report on the performance of the council; • To propose to the council strategies and processes on necessary matters including development planning.	• To support and facilitate the introduction of public transportation system, especially e-bus system in Siem Reap municipality and province; • To include the e-bus system into the wider transport network of Siem Reap municipality/ province; • To facilitate the establishment of an e-bus system in consultation with relevant authorities and stakeholders; • To facilitate the selection of public and private partners to operate the e-bus system.
Ministry of Tourism	• To formulate national policies and strategies on tourism; • To encourage investment in tourism on the basis of the National Strategic Development Plan; • To manage, support, and promote the Cambodian tourism industry and services; • To manage and maintain natural/man-made tourist resorts and tourist centers; • To issue tourist business licenses to tourism companies, agencies, tour guides, hotels, restaurants, means of tourist transport, tourist exploitation services, etc; • To establish, improve and maintain standards and quality of the tourism industry and services.	• To facilitate and promote the use of e-buses for tourists in connection with major tourist destinations and the airport; • To recommend bus routes and stops and facilitate the connection points for an e-bus system which can link to tourist areas. • To promote the concept of green tourism and the image of Siem Reap city as green and smart city. • To promote and encourage private investment in e-buses.
APSARA	• To ensure the protection and preservation of the Angkor Archaeological Park and national cultural properties in the region of Siem Reap/ Angkor; • To design and lead the development of cultural tourism of the region of Siem Reap/ Angkor.	• To promote the use of e-buses in the region of Siem Reap/Angkor to reduce negative impacts of GHG emissions from ICE vehicles on the monuments and to protect the environment; • To restrict the use of ICE vehicles in the region of Siem Reap/ Angkor;

		• To integrate the e-bus system into the sustainable tourism development plans of the region of Siem Reap/ Angkor.
Institute of Standards of Cambodia, Ministry of Industry, Science, Technology, and Innovation	• To prepare national standards for products, commodities, materials, services; • To operate conformity assessment schemes in accordance with provisions set out by law; • To certify the conformity and safety of products, commodities, substances, materials and equipment for local consumption and export; • To provide training and consultancy services to promote standardization and quality; • To cooperate with local authorities, industries, commercial and trade sectors to ensure implementation of standards.	• To prepare, provide, and certify the standards for e-bus and ITS technologies and accessories such as batteries; • To cooperate with local authorities, industries, commercial and trade sectors to ensure implementation of standards for e-buses and accessories.
Electricity Authority of Cambodia (EAC)	• To regulate the electric power services and govern the relation between the delivery, receiving and use of electricity; • To issue the regulations and licenses to electric power services; • To review the cost and approve the tariff.[53]	• To facilitate the electricity connection to e-bus charging stations; • To provide licenses and an MoU for the installation and use of electricity for e-bus charging stations; • To ensure the stable supply of electricity to charging stations; • To provide preferential rights to use electricity and lower electricity tariff for public use.
Electricite Du Cambodge (EDC)	• Responsible for generation, transmission, and distribution of electric power; • To export electricity to and import electricity from neighboring countries; • To construct and operate the national electric grid for energy transmission; • To construct and operate sub-transmission systems for distribution of electricity and to facilitate connections and operations of EDC and other distribution systems;	

[53] https://www.eac.gov.kh/site/responsibility?lang=en

	• To sell electric power and other related services; • To purchase, transfer, and exchange electricity from other regenerators.	
General Department of Customs and Excise	• Responsible for any legal action pertaining to duty levied by the government on any imported and exported goods; • To manage, control and levy taxes and fare on any imported and exported goods; • To curb and prevent any kind of act regarding customs wrongdoings; • To facilitate international trade.	• To facilitate the exemption and reduction of levies, taxes, and fares on the import of e-bus and its accessories; • To facilitate customs clearance and procedures of e-buses and accessories.

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