



Accelerating the Transition to Sustainable Mobility and Low Carbon Emissions in Panama City



Fourth Progress Report: Deliverable 2.3 Economic Assessment

Prepared for the United Nations Industrial Development Organization and the
Climate Technology Centre & Network

LOGIOS



This document was commissioned to LOGIOS, LLC by the CTCN via the United Nations Industrial Development Organization (UNIDO), as part of contract 3000057328. Research, interviews, data collection, analysis, and documentation under this project were conducted by LOGIOS, LLC. Reference herein, direct or indirect, to any specific commercial product or service does not necessarily constitute or imply its endorsement by LOGIOS, UNIDO, or CTCN.

LOGIOS, LLC is a company dedicated to clean energy innovation, integration and implementation (www.logios.global).

Cover photograph: View of Avenida Balboa, Panama City, Panama (2018). © LOGIOS.

(Page intentionally left blank.)

Acknowledgments

The work documented in this report would not have been possible without the invaluable assistance of many stakeholders in Panama, including the Ministerio de Ambiente (MiAmbiente), the Secretaría de Energía, Transporte Masivo de Panamá (MiBus), Alcaldía de Panamá, Elektra Noreste S.A. (ENSA), and AES Panamá S.R.L. The constant assistance of Mr. Ramiro Salinas Revollo and Mr. Federico Villatico, with the Climate Technology Centre & Network (CTCN), is greatly appreciated.

(Page intentionally left blank.)

Table of Contents

LIST OF FIGURES	9
LIST OF TABLES	11
EXECUTIVE SUMMARY	13
1. INTRODUCTION	20
2. FRAMEWORK FOR THE ANALYSIS	21
PROJECT VIABILITY AND RISK ANALYSIS	24
3. CASH FLOW ANALYSIS	28
4. ELECTRIC BUS SYSTEMS ECONOMICS AND GRID INTEGRATION	31
COST OF ELECTRICITY IN PANAMA	33
INTERTEMPORAL FACTORS IN DISPATCH	36
LONG-TERM CONTRACTS AND IMPACT ON ELECTRICITY PRICES	37
NODAL AND REGIONAL PRICING	37
ELECTRIC BUS SYSTEMS AND GRID SERVICES	38
ANCILLARY SERVICES AND ELECTRIC BUS CHARGING STRATEGY	47
5. ASSET VALUATION METHODOLOGY	48
REAL-OPTIONS ANALYSIS	48
WEIGHTED AVERAGE COST OF CAPITAL	50
6. STOCHASTIC ANALYSIS OF FUEL PRICES	54
7. COST ANALYSIS	68
ASSET SERVICE LIFE AND MAINTENANCE PRACTICES	70
REFUELING INFRASTRUCTURE	73
FUEL COSTS	75
TANGIBLE ASSETS: COST AND DEPRECIATION	77
CASH FLOWS AND BINOMIAL LATTICES	78
8. TECHNOLOGY SYSTEM VALUATION FOR THE SELECTED ROUTES	82
THE CHOMA SERVICE ROUTE	82
DIESEL TECHNOLOGY	82
BRIEF INVESTIGATION OF THE OVERNIGHT CHARGE ELECTRIC BUS	91
OTHER SERVICE ROUTES	93
9. FINAL REMARKS	98
APPENDIX 1	100
SUPPLEMENTARY FIGURES	100

List of Figures

FIGURE 1. VISUALIZATION OF THE CORRELATION OF ELECTRICITY SPOT PRICES FOR ENSA AND EDECHI	34
FIGURE 2. VISUALIZATION OF THE CORRELATION OF ELECTRICITY SPOT PRICES FOR ENSA AND EDEMET	34
FIGURE 3. FREQUENCY DEVIATIONS FOR THE FIRST TWO WEEKS IN THE MONTH OF JANUARY IN THE YEARS 2015 (BOTTOM) AND 2018 (TOP), IN THE NATIONAL GRID SYSTEM (DATA SOURCE: NATIONAL GRID)	40
FIGURE 4. HISTOGRAMS OF FREQUENCY DEVIATIONS FOR THE FIRST TWO WEEKS IN THE MONTH OF JANUARY IN THE YEARS 2015 (LEFT) AND 2018 (RIGHT) IN THE NATIONAL GRID SYSTEM (DATA SOURCE: NATIONAL GRID)	41
FIGURE 5. FIVE-YEAR HISTORICAL OF CLEARING PRICES OF REGULATION MARKET CAPABILITY AND REGULATION MARKET PERFORMANCE FOR PJM. DATA SOURCE: PJM.	44
FIGURE 6. FIVE-YEAR HISTORICAL CLEARING PRICE CREDITS FOR REGULATION SERVICES IN PJM, FOR THE CASE OF ONE REPRESENTATIVE ELECTRIC BUS. (DATA SOURCE: PJM).	44
FIGURE 7. SAMPLE DATA OF ACCEPTED AVAILABILITY FEE, CAPACITY AVAILABLE, AND ASSET TYPE FOR PRIMARY FREQUENCY RESPONSE SERVICES IN THE NATIONAL GRID TERRITORY (DATA SOURCE: NATIONAL GRID)	46
FIGURE 8. COST CURVE FOR FREQUENCY RESPONSE SERVICES FOR ONE MONTHLY PERIOD IN THE NATIONAL GRID TERRITORY (DATA SOURCE: NATIONAL GRID)	46
FIGURE 9. STRUCTURE OF A BINOMIAL LATTICE, WITH HYPOTHETICAL VALUES	50
FIGURE 10. HISTORICAL PRICES OF GASOLINE AND DIESEL IN PANAMA.	55
FIGURE 11. SIMULATIONS OF THE FUTURE EVOLUTION OF THE PARITY PRICES OF DIESEL FOLLOWING A GBM	58
FIGURE 12. DISTRIBUTIONS OF DIESEL LOG PRICES AT 24, 48, AND 96 MONTHS, BASED ON GBM SIMULATIONS	58
FIGURE 13. SIMULATIONS OF THE FUTURE EVOLUTION OF THE PRICES OF COMPRESSED NATURAL GAS FOLLOWING A GBM	59
FIGURE 14. HISTORICAL WHOLESALE ELECTRICITY PRICES FOR THE THREE DISTRIBUTION COMPANIES IN PANAMA.	60
FIGURE 15. HISTORICAL RETAIL ELECTRICITY TARIFF IN THE ENSA SERVICE AREA, MTD AND MTH (DATA SOURCE: AUTORIDAD NACIONAL DE SERVICIOS PÚBLICOS)	61
FIGURE 16. SIMULATIONS OF THE FUTURE EVOLUTION OF ELECTRICITY RATES IN THE MTD TARIFF, FOLLOWING A GBM	62
FIGURE 17. DISTRIBUTIONS OF ELECTRICITY RATES IN THE MTD TARIFF AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	62
FIGURE 18. SIMULATIONS OF THE FUTURE EVOLUTION OF DEMAND CHARGES IN MTD TARIFF, FOLLOWING A GBM	63
FIGURE 19. DISTRIBUTIONS OF DEMAND CHARGES FOR MTD TARIFF, AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	63
FIGURE 20. SIMULATIONS OF THE FUTURE EVOLUTION OF ELECTRICITY RATES IN OFF-PEAK MTH TARIFF, FOLLOWING A GBM	64
FIGURE 21. DISTRIBUTIONS OF ELECTRICITY RATES IN THE OFF-PEAK MTH TARIFF AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	64
FIGURE 22. SIMULATIONS OF THE FUTURE EVOLUTION OF DEMAND CHARGES IN OFF-PEAK MTH TARIFF, FOLLOWING A GBM	65
FIGURE 23. DISTRIBUTIONS OF DEMAND CHARGES FOR OFF-PEAK MTH TARIFF, AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	65
FIGURE 24. SIMULATIONS OF THE FUTURE EVOLUTION OF ELECTRICITY RATES IN THE ON-PEAK MTH TARIFF, FOLLOWING A GBM	66
FIGURE 25. DISTRIBUTIONS OF ELECTRICITY RATES IN THE ON-PEAK MTH TARIFF AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	66

FIGURE 26. SIMULATIONS OF THE FUTURE EVOLUTION OF DEMAND CHARGES IN ON-PEAK MTH TARIFF, FOLLOWING A GBM	67
FIGURE 27. DISTRIBUTIONS OF DEMAND CHARGES FOR ON-PEAK MTH TARIFF, AT 30, 60, AND 120 MONTHS, BASED ON GBM SIMULATIONS	67
FIGURE 28. ENERGY CONSUMPTION FOR BATTERY ELECTRIC BUS CONFIGURATIONS ON EACH OF THE EVALUATED SERVICE ROUTES	69
FIGURE 29. ENERGY CONSUMPTION FOR FOSSIL-FUELED BUS PLATFORMS ON EACH OF THE EVALUATED SERVICE ROUTES	69
FIGURE 30. IDENTIFICATION OF POSSIBLE LOCATIONS FOR SHARED OVERHEAD CHARGING EQUIPMENT IN THE MIBUS SYSTEM (SOURCE: MIBUS MAP, EDITED BY LOGIOS).	75
FIGURE 31. HISTORICAL PRICES OF LIQUEFIED NATURAL GAS EXPORTS FROM THE UNITED STATES	76
FIGURE 32. VARIATION IN STATE OF CHARGE OF THE BATTERY OF OVERHEAD CHARGE ELECTRIC BUS OVER THE DISTANCE OF THE CHOMA SERVICE ROUTE, DURING A HIGH-DEMAND PEAK-HOUR CYCLE.	80
FIGURE 33. VALUE LATTICE OF THE DIESEL BUS OPERATING ON THE CHOMA SERVICE ROUTE, WITH DIESEL PRICES, IN BALBOAS PER LITER, BETWEEN PARENTHESES (VALUES ROUNDED TO THE NEAREST 1,000).	83
FIGURE 34. VALUE LATTICE OF THE CNG BUS OPERATING ON THE CHOMA SERVICE ROUTE, WITH CNG PRICES, IN BALBOAS PER LITER EQUIVALENT, BETWEEN PARENTHESES (VALUES ROUNDED TO THE NEAREST 1,000).	84
FIGURE 35. VALUE LATTICE OF THE OVERHEAD CHARGE ELECTRIC VEHICLE OPERATING ON THE CHOMA SERVICE ROUTE, WITH THE PRICES OF THE KILOWATT-HOUR IN THE MTD TARIFF, IN BALBOAS, BETWEEN PARENTHESES (VALUES ROUNDED TO THE NEAREST 1,000).	85
FIGURE 36. VALUE LATTICE OF THE OVERHEAD CHARGE ELECTRIC VEHICLE OPERATING ON THE CHOMA SERVICE ROUTE, WITH PRICES SET VIA LONG-TERM AGREEMENT, IN BALBOAS PER KILOWATT-HOUR, BETWEEN PARENTHESES (VALUES ROUNDED TO THE NEAREST 100).	86
FIGURE 37. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE CHOMA ROUTE	87
FIGURE 38. BOX WHISKER PLOTS OF THE LATTICE OF CASH FLOWS FOR THE DIESEL TECHNOLOGY SYSTEM ON THE CHOMA SERVICE ROUTE	88
FIGURE 39. BOX WHISKER PLOTS OF THE LATTICE OF CASH FLOWS FOR THE CNG TECHNOLOGY SYSTEM ON THE CHOMA SERVICE ROUTE	88
FIGURE 40. BOX WHISKER PLOTS OF THE LATTICE OF CASH FLOWS FOR THE OVERHEAD BATTERY ELECTRIC TECHNOLOGY SYSTEM, WITH REGULATED ENERGY PRICES, ON THE CHOMA SERVICE ROUTE	88
FIGURE 41. BOX WHISKER PLOTS OF THE LATTICE OF CASH FLOWS FOR THE OVERHEAD BATTERY ELECTRIC TECHNOLOGY SYSTEM, WITH LONG-TERM ENERGY PRICES, ON THE CHOMA SERVICE ROUTE	89
FIGURE 42. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE CHOMA IN THE REFERENCE SCENARIO	90
FIGURE 43. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE CHOMA, USING A LIBOR = 3 INTEREST RATE FOR THE BATTERY ELECTRIC TECHNOLOGY SYSTEM	90
FIGURE 44. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE CHOMA, WITH A 10% INCREASE IN THE RETAIL PRICE OF THE OVERHEAD BATTERY ELECTRIC BUS	91
FIGURE 45. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE MAMPK ROUTE, ASSUMING A SHORTER DAILY DISTANCE.	92
FIGURE 46. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE MAMPK, ASSUMING A SHORTER DAILY DISTANCE.	92
FIGURE 47. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE MAMPK ROUTE	93
FIGURE 48. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE MAMPK	93

FIGURE 49. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE CSFAL ROUTE	94
FIGURE 50. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE CSFAL	94
FIGURE 51. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE SIRTIC ROUTE	95
FIGURE 52. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE SIRTIC	95
FIGURE 53. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE DOMAL ROUTE	96
FIGURE 54. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE DOMAL	96
FIGURE 55. SUMMARY OF RESULTS OF THE VALUATION OF THE TECHNOLOGY SYSTEMS CONSIDERED FOR THE TOSAL ROUTE	97
FIGURE 56. OPERATING COSTS INCLUSIVE OF DEBT PAYMENTS FOR FIRST AND LAST MONTH, FOR EACH TECHNOLOGY SYSTEM ON ROUTE TOSAL	97
FIGURE 57. HISTOGRAM OF THE REGULATION CLEARING PRICE CREDITS FOR THE CASE OF ONE REPRESENTATIVE ELECTRIC BUS.	100

List of Tables

TABLE 1. EXAMPLES OF BONDS AND GREEN BONDS ISSUED BY UTILITIES	52
TABLE 2. SCENARIOS FOR THE ESTIMATION OF WEIGHTED AVERAGE COST OF CAPITAL	53
TABLE 3. AVERAGE OPERATIONAL CHARACTERISTICS OF OVERNIGHT-CHARGING BUSES ON EACH OF THE EVALUATED SERVICE ROUTES	68
TABLE 4. OPERATIONAL CHARACTERISTICS OF OVERHEAD-CHARGING BUSES ON EACH OF THE EVALUATED SERVICE ROUTES DURING THE MOST DEMANDING PEAK-HOUR CYCLES	68
TABLE 5. TYPES OF THE ROUTES INCLUDED IN THE TECHNICAL ANALYSIS	73
TABLE 6. ITEMIZED ASSUMED COST OF INSTALLATION OF A COMPRESSED NATURAL GAS STATION	74
TABLE 7. FACTORS INCLUDED IN THE CALCULATION OF CASH FLOWS FOR EACH TECHNOLOGY PLATFORM	78

(Page intentionally left blank.)

Executive Summary

This report presents a comparative economic analysis of battery electric, diesel Euro VI, and compressed natural gas (CNG) Euro VI bus technology systems for public transport applications, for the specific context of Panama City. The analysis uses an asset valuation general methodological framework. As valuation should be based on robust data and information, the analysis builds upon the results of the technical evaluation of the technology systems of interest which were presented in a separate report. **The technical evaluation that accounts for real conditions under which the technology system will operate, is a critical step to enable sound economic and financial analysis.**

Because the timescale of assets' lifetime is typically a decade or more, uncertainties are *inherent* to asset valuation. This affects assets for public transport and, for new-technology systems like battery electric buses, it can be compounded by uncertainties related to the technology. Given the **centrality of risk** in the economic evaluation of technology assets, it is intriguing that most earlier analyses of the economics of electric vehicle systems have largely ignored it. For the most relevant uncertainties to this type of analysis, such as those related to the future evolution of fuel prices, carbon price, etc., using adjusted cash flows is the preferred alternative for the integration of risk into the analysis.

Many types of projects give managers opportunities to use information that becomes available to them at specific points in the process, to exercise *options* to take the investment in certain directions. Whenever such decision points exist, the valuation of the investment ought to account for them. Examples of such decision points, or *options*, include the expansion of the investment, the deferring of an investment, the abandoning of the project, the change of a technology, etc. Traditional discounted cash flow (DCF) methodologies are unable to capture the latent value of options. The most prominent method, adopted for this analysis, is known as *Real Options Analysis* (ROA).

Ultimately, a central goal of this report is to present information that can help Panama develop an investment strategy to integrate clean technologies into its public transport system. The scale of investment needed to transform the transportation sector in Panama and globally is such that cannot be attained without the participation of private capital. Prospective investors will need sufficient assurances of the technical feasibility as well as economic viability and financial sustainability.

Investors' and operators' perception of risk requires special attention in investment strategies involving new technologies, such as battery electric buses. Two key risks are briefly discussed:

- **Technical/technological completion risks.** These relate to the potential inability of the technical processes or technologies involved in the project to meet the expected performance requirements. This risk is directly related to the quality of technology analysis and planning. Transit agencies, lenders (private, government,

philanthropic, concessional, etc.), and shareholders need to be aware that investments in electric bus systems, unless they are preceded by a technical analysis and planning that is able to develop reliable projections of vehicle performance in local conditions, will bear a high technology risk.

- **Economic risks.** One aspect that affects economic risks is the efficiency of the operations. This risk is intimately intertwined with the technical risk: to the extent that careful technical analysis and planning is not conducted, it will be difficult to develop reliable forecasts of energy and power demand, and ultimately of cash flows.

The analysis anticipates the interest of prospective investors in understanding the relationship between investment and future cash flows, assessing the risks, and determining the cost of capital. The capitalization of physical assets, like buses and refueling equipment and the tax effects on cash flows will be included with a proposed treatment of accelerated depreciation. The evaluation of incremental after-tax cash flows includes consideration of the net initial investment outlays, the net operating cash flows, the non-operating cash flows, and the net cash flows from net salvage value.

Critical to the economics of electric bus systems is their **integration with the electric grid** and the latent value streams that arise from such integration. Key to doing a valuation of electric bus systems is to try to understand how to minimize the value that they draw from the grid and how to maximize the value they provide to the grid. For electric bus systems to integrate with the grid, the availability of a system of price signals is critical, so that electric bus systems can interact with the grid in ways that create value for both systems. Price signals are generally provided by the system operator via a market for *ancillary services*. Ancillary services markets have not developed in Panama, yet. Battery systems, including electric buses, are specially poised to provide a frequency response services. In simple terms, frequency response is the fast reaction of a grid resource to deviations in system frequency, to maintain frequency close to statutory limits (60 Hz in Panama). Increasing deployments of non-synchronous generators, such as wind farms, pose challenges to the frequency of the system. Battery storage systems' ability to support frequency response can thus help with the integration of renewable sources of power. The extent to which the latent value streams can be exploited will depend on the quality of the planning prior to procurement and deployment, as well as on local institutional frameworks.

In Panama, **electricity rates** are determined by the Autoridad Nacional de los Servicios Públicos (ASEP). **Power generation** capacity is not expected to present challenges to the development of electric vehicle markets in Panama. Generation, however, takes the lion's share of the cost of electricity, accounting for about 70 cents of every Balboa. According to a recent study, the cost of electricity in Panama is among the highest in Latin America. Increases in power supply since 2010 have come in part from hydropower, but also from a resurgence in the use of petroleum fuels and coal, putting pressure on carbon emissions. **Transmission** capacity has presented some challenges for power delivery, as supply tried to keep up with demand growth. Recent investments have greatly expanded the capacity of the transmission system. The last phase of deployment of the Fourth Transmission Line

(Cuarta Línea) is taking place at the time of writing this report, connecting the generation centers in western Panama, mostly renewable energy plants, with consumption centers in central Panama. There is increasing interest among power generators in Panama to enter into **long-term contracts** with large users for the sale of electricity. As confirmed by the results of this analysis, these are instruments with great potential for electric bus fleets to reduce operating costs, while hedging themselves from price volatility.

While electric buses still imply higher initial capital expenditures, they create opportunities for systems integration and lower operating and maintenance costs on a per-kilometer basis. As described in the technology evaluation report, the extent of these competitive benefits depend on the operational conditions and the appropriate design of the technology system to serve a given route. The extent to which this technology efficiency advantage can be translated into economic/financial advantage is analyzed here for the case of Panama City.

The historical evolution of petroleum-derived prices in Panama, shown in Figure 10, reveals the exposure to price volatility of diesel fleets. To evaluate operating cash flows, projections of fuel prices over the expected useful life to the vehicles that account for volatility are needed. Often, analyses of the expected cost of operation of vehicles have erroneously used a *single value* to represent the future price of fuel. **Stochastic processes** following Geometric Brownian Motions are used to simulate the progressions of diesel, natural gas, and electricity prices over a time horizon of 120 months. Figure 11, for example, illustrates 2,000 such simulations for the case of diesel parity prices.

Considering their respective **charging strategies**, it is sensible to use off-peak MTH rates for overnight charge electric buses, and MTD rates for overhead charge electric buses. This optimization is particularly important to mitigate the economic impact of demand charges.

The technology evaluation, included in a separate report, focused on, that were selected for the evaluation of technical. The technical evaluation, presented in a separate report, developed projections of performance under real-world local conditions of operation, for ten public transport service routes in Panama City, of both overhead charge and overnight charge technology configurations, as well as diesel Euro VI and CNG Euro VI platforms. The results made clear that efficiencies can vary significantly, even *for the same bus*, depending on the operational context (drive cycles, route elevation profiles, passenger loads, etc.). This is the primary reason why conducting detailed technology assessments prior to procurement is so critical, to analyze technical viability and economic efficiencies.

Based on multiple data points from various reports and anecdotal evidence from projects in different locations, a conservative estimate of B/. 0.20/ km is used for the **maintenance cost** of battery electric buses. An economic uncertainty affecting this technology is the rate of degradation that the battery pack will attain over its useful life. For the present analysis, it is assumed that the bus unit has a useful life of 10 years. This assumption is justified to the extent that units can be reassigned, if needed, to routes with lower energy requirements for the last 1-2 years. Data provided by MiBus suggests that the maintenance cost of diesel buses operating on trunclal routes is in the order of B/. 0.40/km, while for

buses operating on corridors these estimates would decrease to about B/. 0.15/km. The maintenance cost of CNG buses are higher, and in this analysis they are assumed to be 1.3 times those of diesel buses.

The table below shows the assumptions used for the prices of capitalized assets before VAT, and other factors included in the **cash flow analysis**. Notice that health costs, primarily from contributions to ambient air contamination, have not been included in the analysis due limited information.

Factor	Overnight charging electric bus	Overhead charging electric bus	Diesel bus Euro VI	CNG bus Euro VI
Bus cash expenditures	\$400,000	\$320,000	\$220,000	\$205,000
Charging equipment cash expenditures	\$40,000	\$160,000		
Fueling station cash expenditures			\$80,000	\$445,000
Importation fees	0	0	0	0
VAT	7%			
Corporate tax	25%			
Development costs	\$10,000	\$80,000	\$80,000	\$110,000
Electricity fuel	Stochastic (MTH off-peak tariff)	Stochastic (MTD tariff)		
Demand charges	Lineal (MTH off-peak tariff)	Lineal (MTD tariff)		
Long-term electricity tariff	Lineal	Lineal		
Fossil fuel prices			Stochastic	Stochastic
Bus work order maintenance	\$0.20/km	\$0.20/km	\$0.35/km	\$0.45/km
Fueling equipment repair	\$10/month	\$100/month	\$500/month	\$500/month
Depreciation	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years
Grid services	-	-		
Carbon price	\$10/ton CO ₂			
Health costs			-	-
Resale value	0	0	0	0

The uncertainties incorporated in the analysis are those in the evolution of prices of electricity, diesel, and natural gas. A *binomial lattice* is used for the discretization of the discounted expected future cash flows, accounting for the volatility in any of the underlying processes. Cash flows are calculated for each of the nodes in the binomial lattice and then discounted to the present. The value of the investment is thus estimated and its viability is assessed.

Since the focus is on the *comparative* economics of battery electric buses vis-a-vis diesel Euro VI and CNG Euro VI buses, the analysis can concentrate on the key factors affecting

cash flow *differentials*. The *differential* median cash flows at a given time step, represent the excess of operating costs of one technology relative to the other, net of operating costs that are common to all technologies. When the differences of cash flows across technology systems are taken, these common costs cancel out. It is important to emphasize that the quality of the cash flow estimates depends heavily on the inputs used in the analysis. The estimates herein developed are based on the in-depth technical evaluation that precedes this report. Missing this type of information, any subsequent economic and financial analysis would be unreliable, and would significantly increase the risk of the related investment plan.

Overnight charge battery electric buses typically charge during off-peak hours at a centralized location. While battery electric buses that charge overnight benefit from significantly lower electricity rates and demand charges, they require low bus-to-charging equipment ratios, typically 1 or 2. In contrast, overhead charging equipment is more capital intensive and has a higher nominal power rating, but they can accommodate much higher utilization rates and higher vehicle-to-charging equipment ratios. The assumption made for the present analysis is that the same charging equipment is shared by 10 battery electric buses. This has implications for the amortization of the initial cash outlays in each case.

The present values of the operating cash flows for each of the technologies, are combined with the respective initial outlays, to produce estimates of the net present value. Even though information about revenues was not available, it can generally be assumed that revenues from all sources are identical for all technology systems, and thus that the net present value before revenues can be used to compare valuations.

The valuation of the technology systems is a central part of the analysis, but not the final step. Investment plan need to be developed, which could include different financing models, given the different characteristics of the technology systems. Preparing detailed investment plans is beyond the scope of the present analysis, but to provide some insight into this process, a discussion of cash flows and debt service payments is included. For the purpose illustration, it is assumed that all technologies can access financing with loans at LIBOR + 9 and 10-year tenor, with a schedule of constant payments on principal and correspondingly decreasing interest payments. Then, the operating cash flows net of debt service can be estimated for each of the technology systems.

The results show that the **relative competitiveness** of CNG Euro VI and overhead battery electric buses depend on the particular characteristics of the route and whether long-term energy contracts are available. Overall, the results show the positive impact of this instrument can have on the economics of the battery electric technology system. The results show that diesel Euro VI buses are at a competitive disadvantage. Sensitivity analysis on interest rates suggest a significant potential for green financing to support the economic competitiveness of battery electric technology systems.

The technical evaluation showed that none of the routes of interest could be served by an overnight electric bus of the configuration considered. Nevertheless, to illustrate the comparative economics of this technology, one of the routes was analyzed assuming a

reduction in daily distance of 50%. For this particular case, it was found that the overnight charge electric bus can be competitive on an operating cash flow basis, but that the cost of the asset makes it less competitive when debt service is accounted for. Making definitive assessments of this technology may require conducting technical evaluations and economic analyses of additional routes.

Below, a list of key considerations arising from the analysis is proposed:

- The analysis demonstrates the **critical importance of conducting detailed technology evaluations** that account for local operational conditions. Economic and financial analyses that would not build upon such evaluations would yield unreliable results. Similarly, investments that are not informed by such evaluations are exposed to significant risks. Pilot projects are not an alternative to technology evaluations; instead they can play an important role in validating the results of evaluations.
- The integration of electric bus systems with the grid can uncover myriad latent value streams. Materializing these value streams will require a modern grid with a system of price signals, organized under institutionally robust markets. Among other, battery electric buses are well poised to provide frequency response services. To support transportation electrification, **Panama should consider developing a modern market for ancillary services.**
- Diesel Euro VI bus systems will have problems maintaining their competitiveness. The results presented here show that they tend to fall behind CNG buses and overhead electric buses on an economic basis. This will be compounded by increasing pressures to put the transportation sector in a trajectory of environmental sustainability.
- From an economic perspective, this analysis shows **no universal winner**. Both overhead battery electric buses and CNG buses are competitive, and which takes precedence depends on a variety of factors, including the operational characteristics of the route, the capital costs of the vehicles, the terms of financing, among others. The results do support the intuitive hypothesis that competitiveness of electric buses increases with utilization; the more kilometers they travel, the more savings they provide.
- The results do provide sufficient grounds to believe that electric buses are a technically and economically viable option for some public transport routes in Panama City. Should the government adopt the strategic position of fostering electromobility, the technical analysis of more routes should be conducted, along with an analysis of operations and of the network of charging locations.
- **Long-term contracts** to firm up the price of electricity are a powerful instrument to enhance the economic competitiveness of electric buses. In fact, the analysis suggests that absent these instruments, it may be more difficult for the battery electric bus to compete with the CNG bus.
- The supply chain for compressed natural gas is not developed in Panama yet. As a consequence, the analysis of the CNG technology system had to rely a larger number of assumptions. It is not obvious, at this point and given the size of the potential market, whether developing the necessary supply chain will ultimately be attractive. The main stakeholder in the natural gas industry in Panama, AES, invested in the

LNG Colón terminal, along with a 381 MW combined cycle power plant, to participate in the electricity market. This suggests that AES may also have a vested interest in the electrification of transportation.

1. Introduction

Large investments, such as the expansion of the Canal and Metro's Line 1 have been key contributors to Panama's economic growth over the last decade. Total investments as a percentage of gross domestic product (GDP) grew from 35% in 2007 before the financial downturn to 43.8% in 2017. These investments, in which the public sector played a critical role, translated into productivity gains and, like in the case of construction projects, into multiplier effects, which ultimately resulted in growth. The investments in the Metro Line 1 and the expansion of the Tocumen Airport Terminal are examples in the transportation sector. As Panama contemplates large investments in clean technologies for public transportation, these macro effects are important to make sound economic and financial assessments. Specifically, Panama may be interested in an evaluation of the impacts of a technological transformation of public transportation on economic and social wellbeing. One central aspect of such evaluation is the valuation of the prospective new technology system vis-à-vis traditional alternatives. The other central aspect is the internalization of the societal/environmental benefits that the new technologies may bring about.

Probably nowhere more than in the economic and financial analyses does the change in paradigm brought about by battery electric buses become apparent. This report will serve to further highlight the dimension of this change, as analyses of battery electric buses are developed alongside analyses of conventional buses. Not only are the value streams in battery electric bus technology systems different, but also more complex, interrelated, and multidirectional. Indeed, we are still in the early stage of understanding the full potential of value streams that could be drawn from electric bus technology systems. For this reason, it is appropriate to approach the economic analysis of these technology systems with an eye on the opportunities; that is, the value streams that *could* be realistically uncovered.

To explicate on a conceptual basis the fundamental differences in the value streams of the technologies of interest and how these value streams ought to be reflected in the economic and financial analysis, we dedicate Section 2 to lay out the framework for the analyses. Section 3 is then dedicated to the framework for cash flow analysis. Section 4 follows with a discussion of the important subject of the integration of electric fleets with the electric grid. This is followed by a discussion of the asset valuation methodology in Section 5. Section 6 is dedicated to the quantitative analysis of fuel prices. Section 7 presents a cost analysis, followed by Section 8 with the economic and financial analysis of battery electric buses vis-à-vis conventional buses for the routes in Panama City. Finally, Section 9 presents the summary of results and final considerations.

2. Framework for the Analysis

The present analysis is grounded on the premise that an electric transportation technology system ought to be viewed as a techno-economic paradigm that is *different* than that of conventional transportation technology systems. This is stated upfront to equip the reader with the appropriate interpretive lens. The fundamental reasons supporting this statement will further unfold over the course of the analysis but, conceptually, this is not difficult to see. The first and most apparent difference is that electric transportation is a disruptor and is a technological system moving along a steep innovation curve. Conventional technology systems centered on the combustion of carbon-intensive fuels, on the other hand, are fairly well established. Another critical difference resides in the complexity of the value streams associated with each technology system. Conventional technology systems are characterized by value streams that generally move in one direction, from a centralized, commoditized, fuel supply system to disaggregated centers of demand that predominantly act as price takers. Electric transportation, instead, is characterized by multidirectional value streams that can flow between disaggregated demand centers and increasingly disaggregated supply centers. These differences limit the validity of apple-to-apple economic comparisons between conventional and electric transportation systems.

The general approach taken in this analysis is one of asset valuation. Asset valuation is used to estimate the present and future value of the assets, using a given methodology. Regardless of the methodology, valuation should be based on robust data and information. This report abides by this principle; it builds upon the results of the technical evaluation of the technology systems of interest — battery electric, diesel, and compressed natural gas (CNG) buses for public transport — which were presented in a separate report. **The technical evaluation that accounts for real conditions under which the technology system will operate, is a critical step to enable sound economic and financial analysis.** Marston et al. (1968) defined asset valuation as “the art of defining the monetary measure of the desirability of ownership of specific properties for specific purpose...”¹ They then complement this definition with an engineering perspective: “... engineering valuation is the art of estimating the value of specific properties where professional engineering knowledge and judgment are essential... based fundamentally upon [the asset’s] ability to produce some kind of useful service during its expected future life in service...”

The value of an asset investment is dependent upon its future cash flows. Evidently, for investments in projects with a strong societal value, such as a clean public transportation system, investment frameworks that contemplate this broader value are appropriate. Approaches to investment that give center stage to societal impacts have become known as impact investment and ESG (environment, social, governance) investments. Regardless, a solid analysis of cash flows is essential for the development of bankable investment plans.

In a simple world in which cash flows are known a priori with relative certainty, the estimation of value reduces predominantly to the determination of discount rates, which

¹ Marston, A., Jean, C. H., and Robley, W. (1963). “Engineering Valuation and Depreciation.” Iowa State University Press.

are then used to estimate the present value of the future cash flows. Methodologically, this means estimating the economic performance of a project over its lifetime as a Discounted Cash Flow (DCF), which uses a metric, typically net present value (NPV) or internal rate of return (IRR), to evaluate the financial merits of an investment.

Because the timescale of assets' lifetime is typically a decade or more, however, uncertainties are *inherent* to asset valuation. This affects assets for public transport, and, for new-technology systems, it can be compounded by uncertainties related to the technology. When uncertainty enters the picture, the present value of future cash flows no longer depends just on time; they also depend on the appetite of investors to take on risk. Methodologically, risk enters the analysis via risk premiums in the form of risk-adjusted discount factors, or by adjusting the anticipated cash flows. For uncertainties pertinent to this analysis, such as those derived from the future evolution of prices for fuel, carbon allowances/credits, etc., calculating risk premiums is complex.^{2,3} Using adjusted cash flows is thus the preferred alternative for the integration of risk into the analysis. There are a variety of tools that can be used to account for uncertainties. In the simpler end of the spectrum of tools is sensitivity analysis; in the more sophisticated end is probabilistic analysis via simulation (Monte Carlo). Given the centrality of risk in the economic evaluation of technology assets, it is intriguing that most earlier analyses of the economics of electric vehicle systems have ignored, either largely or completely, the effect of risk.⁴

Many times, investments can be analyzed as involving a single initial decision event. There are many cases, however, in which managers can use updated information available to them at specific points in the process, to exercise an option to take the investment in a given direction. Such multiplicity of decision points can have an impact on the value of the investment, the valuation ought to account for them. Such decision points, or *options*, could include, for example, expand/scale the investment, defer an investment, abandon the project, change a technology, or other. The valuation of options could turn a negative NPV into a positive one, and thus can impact the investment decision. Pure DCF methodologies are unable to capture such latent value, and it is fairly well established that relying on these methodologies for projects that involve options leads to inaccurate valuations.⁵

While estimating the value of these options is rather complex, financial theory has provided the instruments on which the estimation of options value rest. This has led to myriad applications in the investment world, including investment in the energy and technology sectors. The most prominent method to analyze investments with latent decision points is Real Options Analysis (ROA), and it will be further discussed later.

² See, for example, Abadie, L. and Chamorro, J. (2013) *Investment in Energy Assets Under Uncertainty: Numerical Methods in Theory and Practice*. Springer.

³ This complexity derives from the fact that the anticipated cash flows depend on nonlinear underpinning stochastic processes.

⁴ One exception is Burke, A., Collantes, G., Miller, M., and Zhao, H. (2015) *Analytic Tool to Support the Implementation of Electric Vehicle Programs*. University of California at Davis.

⁵ See, for example, Dixit, A.C. and Pindyck, R.S. (1994) *Investment Under Uncertainty*, Princeton University Press, Princeton, N.J.

Electric bus systems include not only the bus units but also the infrastructure needed to effectively integrate them as part of a modern grid. For the valuation of these systems, accounting for options is important. The lifetime of electric grid assets tends to be in the order of a decade or more. Indeed, grid investments are generally irreversible. For this reason, managers prefer investment schedules with some degree of flexibility, where they can have options at various points to integrate new information into their decision-making process. Put in a different way, the absence of options may significantly reduce the value of a given prospective investment. We formalize this mathematically as follows:

$$NPV_{WO} = NPV_{NO} + OV$$

Where NPV_{WO} and NPV_{NO} are the net present value of the project with and without options, respectively, and OV is the options value. NPV_{WO} is often known as the *strategic value*.

Methodologically, there are three general approaches to the valuation of options: dynamic programming, stochastic differential equations (SDE), and simulation. SDE are often used in the valuation of financial options.⁶ Dynamic programming often takes the form of a binomial lattice and is commonly used for real option valuation. Finally, simulation typically follows Monte Carlo methodologies, to look at a great number of possible paths along which a project can evolve, obtain probabilistic measures, and use these to account for uncertainties. The simulation method is sometimes appealing because it enables the analysis of multiple assets simultaneously and of multiple sources of uncertainty with the same or different probabilistic characteristics.

Although technology innovation takes time, it is clear that the transportation sector is in a trajectory transitioning away from fossil fuels, toward a zero-emission future. The magnitude of the investments needed for this transformation is enormous, and it can only be materialized with a major participation of private capital. Private capital is increasingly attracted to investments that include longer-term softer benefits, such as community wellbeing, in addition to financial short-term returns. Institutional investors who have a vested interest in the community may typically be a candidate for engagement. Such investors may see it to their medium- and long-term benefit, for example, to promote a healthier local community through improvements in air quality.

The expected service life of the battery pack constitutes one of the central uncertainties in the projected cash flows of a fleet electrification. Depending on the degradation rate of the battery cells, their battery pack may need to be replaced before the vehicle reaches its expected service life. This means that the operational phase of the investment plan of buses, regardless of their technology, needs to account for capital expenditures (CAPEX). Anecdotal evidence from a transit agency in Southern California with great experience with battery electric buses, the capacity of the batteries is still at over 90 percent, after 10 years

⁶ This is the line of work following the seminal work of Black, Scholes, and Merton, that arrived at what now is known as the Black-Scholes equation.

of service.⁷ Conventional buses are expected to perform a major overhaul of their drivetrain too, involving the replacement of the engine and transmission, around the 6th or 7th year in service — a fact that is often neglected in comparative analyses of battery electric buses.

For a fleet electrification project, the decision about scope, in time and scale, is complex and extremely important. This importance is often overlooked. Both the real challenges and the potential profitability of these projects become clearer at larger scales. The projection of work in progress (WIP) payments grows nonlinearly with scale, given the different investment needs related primarily to real estate and infrastructure upgrades. The definition of a long-term scope has to be preceded and supported by a careful analysis and planning. It is here where pilot projects can bring the most value, namely helping to validate the results of the technical and economic analyses, thus further strengthening the confidence of prospective investors about the sustainability of the project. Unfortunately, electric bus pilot projects are sometimes implemented before or, worse, *instead* of careful techno-economic analysis and planning. This practice may be due to a limited understanding of the importance of analysis and planning to determine the conditions for viability and efficiency in investments involving battery electric buses in a given location. A big part of the value of the technology assessment conducted for Panama, preceding the present analysis, was precisely in helping understand the type of projects that would be technically viable and efficient for the specific local conditions.

To secure financing for a project under traditional structuring mechanisms, prospective investors need sufficient assurances of the technical feasibility as well as economic viability and financial sustainability. Technical feasibility implies that the project can be implemented according to schedule and within budget, and that it can subsequently operate at the design capacity and within performance requirements. Economic viability implies that the project will generate sufficient cash flows to cover the overall cost of capital. Financial sustainability implies that the project will be able to generate sufficient unlevered free cash flow (UFCF) to exceed the service of the debt. The excess of UFCF over debt service is given by agreed-upon values of metrics such as the appropriate cover ratios. Typically, the higher the (perceived) risk, the higher the value that investors will require for these metrics.

Project Viability and Risk Analysis

Strictly, a project can only prove its viability beyond any reasonable doubt only after it has completed the implementation phase and has been operational for a sufficiently long period of time. For this reason, lending to a project or special purpose vehicle (SPV) before implementation exposes lenders to a variety of risks, real and/or perceived. Lenders are generally not prepared to assume risks related to technology or other business areas on which they do not have expertise, and for this reason, they require security arrangements specifically designed to allocate these risks to suitable parties. The implication is that

⁷ LOGIOS conversation with the transit agency.

lenders will do the due diligence required for them to understand the risks involved in the project. Some of the key types of risks are discussed next.

- a. Financial completion risk. The most typical example of financial completion risk is the underestimation of implementation costs. For economies that are not particularly stable, this can come in the form of uncertain inflation rates or exchange rates over the course of the implementation phase. The longer the implementation phase, the higher this risk would typically be. In the case of Panama, the government has had a central role in the large public investments that have been a driving factor of the spirited economic growth in the last decade that reached USD 61.8 billion in 2017 up from USD 21.9 billion in 2007, and projected to reach USD 97.8 billion in 2023.⁸ At the same time, Panama has the lowest tax revenue in the region, particularly when compared with countries with similar GDP per capita. Assuming the tax base remains the same and accounting for the pipeline of ongoing and planned large public investment projects (e.g. the Metro lines 2 and 3, the 4th high-voltage transmission line, and others), the structuring of the financing packages may have to provide for assurances that funding will be available to meet debt repayment commitments.
- b. Technical/technological completion risks. These relate to the potential inability of the technical processes or technologies involved in the project to meet the expected performance requirements. Even if technology risks may not impair the project completion as described above, there may be a risk that one or more of the technologies involved in the project do not perform according to expectations or they become obsolete during the life of the project. This form of technology risk is relevant in the case of new advanced technologies that are experiencing rapid evolution. Needless to say, bus electrification may be affected by this type of risk, and in fact it has the potential to be a significant obstacle in securing private capital for project financing. Financing packages need to be structured in a way such that lenders are sufficiently hedged against this risk. Technology risks, perceived and real, are relatively high for bus electrification projects, and have the following two facets:
 - i. The risk associated to the technology itself. There is a risk that the bus is not able to deliver the level of service and performance needed for a particular operation. The best way to address this risk is with a careful expert analysis and planning, similar to the technical evaluation conducted for Panama, preceding this analysis. Two real and related risks are the potential underestimation of this technical risk and the limited understanding of the type of analysis that is required to mitigate it. Transit agencies, lenders (private, government, philanthropic, concessional, etc.), and shareholders need to be aware that investments in electric bus systems, unless they are preceded by a technical analysis and planning that is able to develop reliable projections of vehicle performance in local conditions, will bear a high technology risk.

⁸ World Economic Outlook, International Monetary Fund. Accessed in February 2018 at <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/weoselco.aspx?g=205&sg=All+countries+%2f+Emerging+market+and+developing+economies+%2f+Latin+America+and+the+Caribbean>

- ii. The risk associated to the scaling of battery electric bus systems. Risks related to scaling are relevant in fleet electrification projects because the technical challenges can increase significantly with the number of electric buses to integrate in the fleet. This type of risk can be addressed with the development of a long-term plan that includes a technical analysis and integrates the input from relevant stakeholders, such as electrical generation and distribution companies.
- c. Economic risks. The project may be sound from a technical/technological standpoint, may have been completed successfully, and may be operating as desired. Even in such case, the ability of the project to generate sufficient cash flow to cover operating costs, meet the scheduled installments toward debt service, and, if applicable, generate a fair rate of return on equity, may be limited. One aspect that affects economic risks is the efficiency of the operations. This risk is connected with the technology risk discussed above: to the extent that careful technical analysis and planning is not conducted, it will be difficult to develop reliable forecasts of energy and power demand, and ultimately of cash flows.

In the case of early-market technological systems, such as electric vehicle fleets, where operation experience is generally low, investors will demand assurances that both implementation and operational phases will involve personnel with the required experience and technical know-how. A recent report of the International Monetary Fund (IMF, 2017) highlighted among many positive signs of the Panamanian economy, that education and efficiency in the public administration are two key areas for improvement. The transformation of the public transport system provides one opportunity to implement programs of technical training for operators and technicians, to help improve operation efficiency. In 2017, Transporte Masivo de Panamá, MiBus, reported a 9.6 percent growth in the number of trips compared to 2016, thus reaching 3.1 million.⁹ Receipts from excise taxes on gasoline products grew about threefold in the 2010-16 period, reaching 280 million Balboas.¹⁰ In the case of the Metro 1 Line, it was reported that the revenue from fares reached \$26.3M in 2016, falling short by \$1.7M of the cost of financing. That difference was subsidized by the government, although it was announced that the subsidy would end following an increase in passenger fares.¹¹

- d. Raw materials risk. The areas of primary interest in this risk category are the supply of conventional fuels and the supply of power and electricity. As reported by the International Monetary Fund (IMF, 2017), Panama's energy and communications infrastructure is competitive in the regional context. Additional infrastructure assets are added to the transmission side, which would help increase electricity exports to Costa Rica y may open opportunities for exports to South America.¹² These

⁹ <https://www.panamatoday.com/panama/bus-service-associated-panama-metro-grows-96-2017-8925>

¹⁰ <https://stats.oecd.org/Index.aspx?DataSetCode=REVPAN>

¹¹ <https://www.panamatoday.com/panama/fares-and-expansion-challenges-panama-metro-system-2017-2827>

¹² The 3rd high-voltage transmission line is under construction, with an investment level of USD 350 million, while the 4th high-voltage transmission line is planned, with an investment level of USD 450 million.

developments speak to an abundance on the generation side of the grid, although the availability of electricity for the domestic market can depend on the trade agreements. The 2017 World Bank's *Doing Business Index* gave a high grade to Panama in the category *Getting Electricity*. We mention the electricity and communication sector in the same paragraph because they are intrinsically related components of the grid of the future.

- e. Financing risk. Panama has a very competitive financial sector that holds assets at 238 percent of the gross domestic product. This competitiveness is consistent with the low cost of finance, as shows by the low real lending rate relative to Latin America.

3. Cash Flow Analysis

Sponsors of a project involving the procurement of capital assets, such as new technology buses and supporting infrastructure, will be interested in understanding the relationship between investment and future cash flows, assessing the risks, and determining the cost of capital. With this information, the worth and the bankability of the project can be evaluated. Tax considerations are important too, as investors are interested in incremental after-tax cash flows. Tax effects on cash flows can be important whenever the timing of cash flows is tangibly different from the timing of the recognition of such cash flows for tax purposes. Related to these effects is the question of depreciation of capital assets, which will be discussed later in the analysis.

The capitalization of physical assets, such as buses and refueling equipment, will have an impact on the timing of cash flows and therefore understanding the local tax code in this regard is important. In general, because of the cost of capital, project sponsors will prefer to expend the assets rather than to capitalize it, although in some places the tax code requires that certain assets be capitalized, in which case sponsors will prefer to adopt an accelerated depreciation.

The analysis will be concerned with incremental after-tax cash flows. Evaluating these requires consideration of four broad items, which are described below. namely the net initial investment outlay, the net operating cash flows that occur during the operation phase, the non-operating operating cash flows (sometimes including CAPEX), and the net cash flow resulting from the net salvage value. Each is described separately:

A) Net initial investment outlay

This generally involves the following items:

- Cash expenditures (CE): These can be capitalized or expensed. The latter has immediate tax implications. Defining I_0 and E_0 as the net expenditures to be capitalized and expensed, respectively, and IT as the corporate income tax rate, CE is calculated as follows:

$$CE = -I_0 - (1 - IT)E_0$$

Negative signs represent cash outflows. I_0 comprise all costs that will bring benefit over a longer period of time. These include the cost of the bus units and costs incurred to bring the equipment to working condition, such as the supply equipment, all the apparatus for the maintenance of this equipment, grid assets deployed to support the power supply to the charging equipment, all installation costs (including labor, permits, and inspection), and such. Because most of these pieces of equipment will be imported, they will be subject to duties, which for new road vehicles that are used for public transport of passengers and that are not diesel, are specified in code 8702.90.11 of the Panamanian tariff system (Arancel de Importación de la República de Panamá). According to this code, Import Rights Tariff (Derecho Arancelario a la Importación, or DAI) is 0%, the Movable Goods and

Services Transfer Tax (Impuesto sobre la Transferencia de Bienes Muebles y la Prestación de Servicios, or ITBMS) is 7%, and the Selective Consumption Tax (Impuesto Selectivo al Consumo, or ISC) for road vehicles is 5%.¹³ E_0 can include import tariffs, personnel training, site development, and others. The corporate income tax rate in Panama is 25%.¹⁴

- Changes in net working capital
These include any additional cash that may be needed, such as for infrastructure expansions or upgrades as demand increases.
- Net cash flow from sale of retired assets
The sale of used buses and other equipment can generate revenues and expenses, as well as tax implications related to any difference between the sale price and the book value of the assets. The retired asset cash flow (*RACF*) is calculated as

$$RACF = S_0(1 - IT) + IT B_0$$

Here, S_0 is the sale price and B_0 is the book value. In some cases, S_0 may be the cash received for scrapping the old vehicles.

- Investment tax credits: Certain tax instruments, such as investment tax credits (ITC), can have significant impact on private equity participation in investments in clean technology. There are examples of ITC in Panama to support renewable energy, such as the law establishing incentives for construction and operation and maintenance of solar PV plants in Panama.¹⁵ There are no ITC that apply directly to investments in zero-emission transportation, although, as it will be discussed later, the ITC on renewable energy may indirectly benefit battery electric bus fleets, via the establishment of long-term power purchase agreements and the potential certification of well-to-wheels zero-emission public transportation. Returns seen by tax equity investors in solar has been in the range of 7% to 12% after tax IRR unlevered, and have a representative typology of 65% ITC, 14% accelerated tax depreciation, and 22% cash flow. The most typical structuring of tax equity investments takes the form of *Partnership Flip*, in which a *Project Co* is formed to allocate the various tax items and cash flows among investor/s and developer/s. The investors are allocated most of the tax items, to subsequently *flip* down significantly, after the pre-specified IRR is attained. The availability and level of ITC will depend on the local tax code. As discussed above, in certain regulatory environments, project developers may be able to use ITC to generate financing structures, such as tax equity. The developer receives tax credits and can apply the depreciation of its taxable income. In cases when the developers have enough tax appetite and can monetize the tax credits, debt financing can be a good option.

¹³ Crude oil is exempt from ITBMS in Panama.

¹⁴ For companies with taxable revenues over US\$ 1.5 million, an alternative tax may apply.

¹⁵ Law 37 of 2013, amended by Law 38 of 2016.

B) Net operating cash flows

These are the cash flows after tax (CFAT) needed to keep the operations during the life of the project. They are calculated as the difference between changes in revenues (Δr) and expenses (Δe), accounting for all tax liabilities. Tax liabilities will depend, in turn, on the treatment of depreciation; a topic that will be discussed in detail later. Broadly, CFAT is then expressed as follows:

$$CFAT = \Delta r - \Delta e - \text{tax liability}$$

C) Non-operating cash flows

These are cash flows other than those derived from day-to-day operations and will not be given consideration in this analysis.

D) Net salvage value

This is similar to the cash flows from sale of retired assets, described below. It is more general, in that refers to all after-tax cash flows resulting from the termination of the project, such as cleanup, recycling and processing of retiring assets, and others. As it is explained later, it is assumed that the book value of retiring assets, such as end-of-life buses, is zero, and that assumption is used in the treatment of depreciation.

To identify suitable loan amortization approaches, it is critical to make a solid estimation of the expected performance of the unlevered free cash flows, which will be the basis for the negotiation of loan repayment schedules. For this reason, a strong technical analysis is an indispensable step prior to developing an investment plan, to estimate the cash flows needed for the operation of the technology system under specific local conditions. A positive aspect of investments in transportation technology systems, in that the construction phase, which is often a source of important uncertainties for lenders, is comparatively short. Even for the case of battery electric buses, if grid upgrades are necessary, the processes involved in such work are well understood by the incumbent entities and should be amenable to predictable planning.

4. Electric Bus Systems Economics and Grid Integration

This section is concerned with a critical aspect of the economics of electric bus systems, namely their integration with the electric grid and the latent value streams that arise from such integration.

To obtain their fuel, electricity, battery electric buses need to interact with the electric grid. This fact makes battery electric buses part of a system much larger than themselves. The significance of this fact for the economics of this technology is probably insufficiently recognized, and indeed not yet fully understood, given the early stage of the market. A system is composed of parts that interact dynamically. In this sense, the economics of electric bus assets will depend on the characteristics of other components of a particular grid, and the economics of other components will in turn depend on the characteristics of electric bus assets. In fact, operating a grid system efficiently means finding the efficient way to utilize a set of generation and consumption assets. Each generation asset is characterized by a cost function, while consumption assets (or the economic agents behind them) are characterized by utility functions. Key to doing a valuation of electric bus systems is to try to understand how to minimize the value that they draw from the grid (negative cash flows) and how to maximize the value they provide to the grid (positive cash flows).

The preceding discussion suggests a few conclusions, namely:

- a. Total Cost of Ownership, as an approach to understand the economic value of electromobility, is fairly limited;
- b. The potential value of electric vehicle systems is contingent upon the characteristics of the local grid system and cannot be extrapolated from one region to another; and
- c. Technical analysis and pilot projects can be critical to better quantify, test, and further discover these complex value streams.

The interrelation between electric buses and the system that provides electricity is entirely *different* and *more complex* than the relation between conventional combustion buses and the system delivering fossil fuels, such as diesel and natural gas. The most important difference, as the last sentence implies, is that there exists a potential for a bidirectional relation between electric buses and the grid. This bidirectional potential creates opportunities for a variety of value streams. The extent to which such value streams are exploited will depend on the quality of the planning prior to procurement and deployment, as well as on local institutional frameworks.

Planning an electric bus system is a complex process and the opportunities in the connection with the grid are at the center of that complexity. Undertaking the necessary analytic process is entirely indispensable, as it will impact directly on the economics of each electric bus and will have a major effect on the scalability of an electrification strategy. In its most basic form, an analysis of the fuel-related operation costs of electric buses could simply consider the bus, charging for an amount of time equal to the ratio of the estimated needed energy to the nominal power of charge, and exposed to a predetermined cost of

energy. This simplified analytic approach, however common, yields erroneous results and misses the larger picture of opportunities for value streams. It is helpful to decompose these issues a little further.

The starting point in the analysis is the energy demand. Energy demand in turn encompasses energy and timing. The nominal power of charge also has an important effect on charging time, but this effect is in turn strongly affected by other factors, such as the chemistry and architecture of the battery pack. Fast forwarding through some of these complexities, it is of interest to highlight an important concept about the value streams of bus-grid integration: understanding the potential economics of the electric drivetrain requires an understanding of the *local* electricity markets. In particular, this requires an understanding of the system of price signals emanating from the existing markets and infrastructure. The next section starts with a discussion of the price of electricity and power in Panama, to then spend some time discussing other aspects of the market.

In the traditional structure of electrical grids, power is generated centrally in a relatively small number of large generators and delivered to a very large number of end users who, for the most part, are passive, in the sense that they are not able to respond to time-varying market conditions. It is recognized that this structure has to change, as current trends in the grid evolution point to a proliferation of assets in the grid edge: distributed generation, storage, and smart systems. Electric vehicles, light- and heavy-duty, are part of this new landscape and ought to be considered distributed energy resources (DER).

The efficient utilization of this universe of assets in the grid edge requires novel approaches to the management of the distribution networks. Such approaches in fact constitute one of the frontiers of the development of smart grids. They will make use of price signals to optimize supply and demand in a fashion similar to what is done by wholesale system operators, though with a higher degree of complexity. Electric buses represent an opportunity to implement and test some of these concepts in the short term.

The main point of the preceding paragraph is to highlight the importance of understanding a fleet of electric buses not as a set of independent loads, but rather as part of a dynamic system of assets in the distribution system. This understanding is critical not only for the effective integration of electric buses into the grid, but also for extracting the maximum value out of the investment. Because, as stated above, the optimization of the distribution system is based on price signals, regulators and participants in the electricity market will also have an impact on the economics of electric buses in a particular location. In other words, a modern grid that enables grid edge assets to respond optimally to dynamic price signals will be able to extract more value out of electric buses. Central to the notion of modern grids is an evolution in the role of the power industry, which is moving from warrantor of reliability to provider of a market, via generation of price signals, that steer utilization of and investment in grid assets toward system efficiency.

Cost of Electricity in Panama

In Panama, electricity rates are determined by the Autoridad Nacional de los Servicios Públicos (ASEP). Tariffs are broadly structured in the following categories:

- BTS: Low voltage without demand (Baja tensión sin demanda)
- BTD: Low voltage with demand (Baja tensión con demanda)
- MTD: Medium voltage with demand (Media tensión con demanda)
- MTH: Medium voltage hourly (Media tensión horaria)
- ATD: High voltage with demand (Alta tensión con demanda)
- ATH: High voltage hourly (Alta tensión horaria).

The BT bracket corresponds to users with connections up to 15 kilovolts, the MT bracket includes users connected to over 600 volts and under 115 kilovolts, and the AT bracket corresponds to users in lines on 115 kilovolts lines. Within brackets, tariffs are structured stepwise. The tariff step structure in the BTS bracket is as follows:

- BTS1, if consumption is up to 350 kilowatt-hour (kWh)
- BTS2, if consumption is over 350 kWh and up to 750 kWh
- BTS3, if consumption is over 750 kWh.

Government subsidies further encourage conservation among customers in the BTS1 bracket, by defining seven 50 kWh sub-brackets, from 0 to 350 kWh, and increasing rates as consumption moves from the lower to the higher sub-brackets. Although these structures were designed to foster efficient use of energy, Panama will need to revise them as it develops a strategy to support the growth of electromobility.

The rates for each kilowatt-hour in Panama have generation, transmission, and distribution components. The end-user may see some volatility on the generation component, which necessarily reflects the variation in costs of power generation with seasons (for example, dry and wet seasons for hydropower), with commodity markets (for example, cost of crude oil), etc. This volatility is not seen by the end-user on an hourly or daily basis. Instead it is aggregated and passed through as monthly rate adjustments.

Rates also vary across service territories, each serviced by the companies EDEMET, ENSA, or EDECHI. Rates can also vary significantly depending on the month, particularly for the areas services by EDEMET and ENSA. Figure 1 serves to visualize the significant correlation between spot prices for ENSA and EDEMET, while Figure 2 shows a poor correlation between spot prices for ENSA and EDECHI.

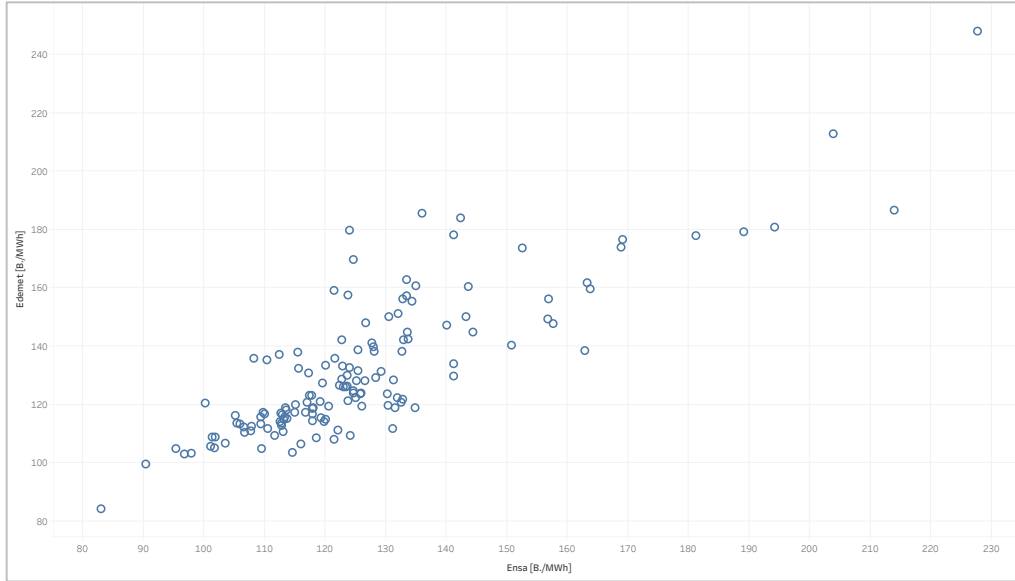


Figure 1. Visualization of the correlation of electricity spot prices for ENSA and EDECHI

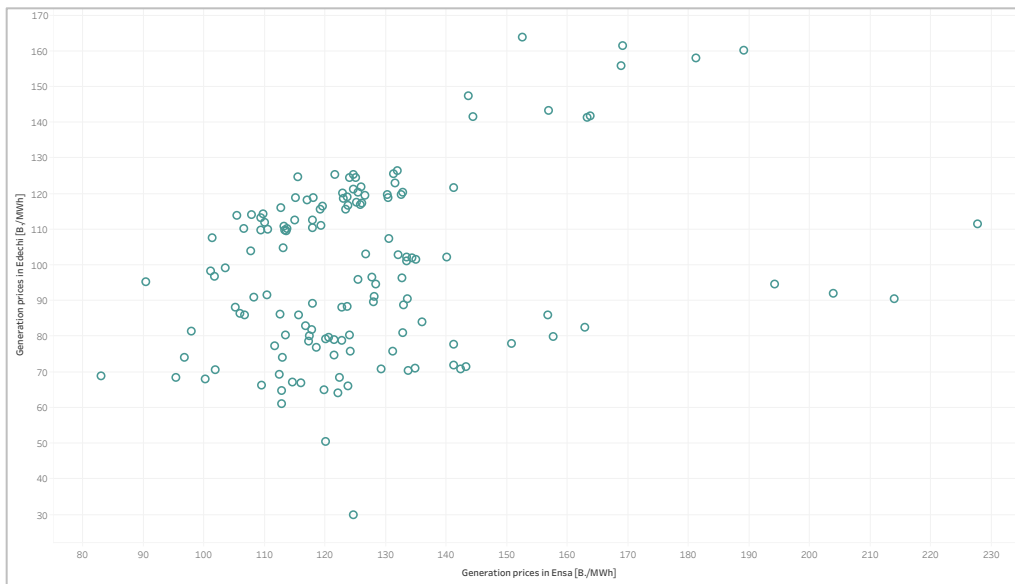


Figure 2. Visualization of the correlation of electricity spot prices for ENSA and EDEMET

Generation capacity is not expected to present any challenges to the development of electric vehicle markets, as there is already spare capacity, more baseline capacity is coming online within the next couple of years, and renewable energy developments continue to grow. Generation, however, takes the lion's share of the cost of electricity in Panama, accounting for about 70 cents of every dollar. The economic growth that Panama experienced also put pressure on electricity demand, and consequently on prices. The resulting increase in supply came in part from hydropower, but also from a resurgence in the use of petroleum fuels and coal, which Panama had ceased using for power generation by 2010. Hydropower has a central role in the supply of electricity, but the remote location

of hydroelectric plants make transmission expensive. In addition, generation prices from hydro vary significantly over the year with variations in rainfall, which has historically affected the volatility of spot market prices. It is expected that recent investments in combined-cycle heat and power natural gas plants will help alleviate this volatility. Tariffs in Panama also included a fuel variation charge (CVC, for their name *Cargo de Variación por Combustible*) that integrates variations in the price of petroleum. The CVC is a hedging mechanism against uncertainty in petroleum prices and translates into an increment in the price or as a credit to customers, depending on whether the price of petroleum is over or under the projected price.

The Panamanian transmission company, ETESA, prepares and continuously updates a long-term plan with a 15-year time horizon, to project growth in demand, including the effect of possible disruptive developments. Based on this plan, ETESA evaluates the investments needed to support the projected demand. ETESA is aware of the prospective electrification of road transportation, and in principle has been evaluating scenarios of market penetration starting with public transportation buses, followed by high-end personal vehicles. At the moment of writing this report, ETESA did not have quantitative estimates of the projected demand, and would be an avid consumer of studies that shed light into these questions.¹⁶

Transmission capacity has presented some challenges for power delivery, as supply tried to keep up with demand growth. Recent investments, with participation of generation companies, have greatly expanded the capacity of the transmission system. The last phase of deployment of the Fourth Transmission Line (Cuarta Línea) is taking place at the time of writing this report, connecting the generation centers in western Panama, mostly renewable energy plants, with consumption centers in central Panama. The capacity of this line has been upgraded from 230 a 500 volts. As new natural gas generation capacity is coming online, there are some concerns about the potential for bottlenecks in the transmission system.

A number of incidents have been registered, including substation explosions, that resulted in significant outages in regions in Panama.^{17,18,19} In some cases, these events have affected the operations of the Panama Metro, exemplifying the potential impacts that outages can have on transportation, if and as this sector moves toward electrification, and suggests the need for further investments in grid reliability. Over 70 percent of the demand for electricity resides in Provincia de Panamá, in the center east, while much of the generation is located in the western parts of Panama. As transportation electrification will predominantly start in metropolitan areas in Provincia de Panamá, the need for a reliable transmission system connecting the two regions becomes apparent.

¹⁶ Conversation with ETESA representatives.

¹⁷ https://www.prensa.com/sociedad/Piezas-danadas-parcial-Panama-Colon_0_4713278717.html

¹⁸ https://www.prensa.com/sociedad/Fallo-subestacion-Penonome-provincias-Metro_0_4789770996.html

¹⁹ https://www.prensa.com/sociedad/Incidencia-provoca-parcial-Panama-Etesa_0_4792770694.html

From the perspectives of infrastructure and economics, the electrification of public transport and personal mobility involve distinct elements that require separate consideration. The general public, who will prospectively be the primary adopter of light duty vehicles, represents by far the largest end-user population. Actual power demand, however, is dominated by a relatively small group of slightly over 80 large end-users with 100 kW or more of power demand.²⁰

In Panama, the operator of a fleet of battery electric buses could face demand charges that depend on a contract and are proportional to the maximum value of the power used for charging during a given month. This means that the monthly demand charge does not necessarily depend on the *nominal* power of the equipment, but on the *actual* power consumed.²¹ This distinction can be important as it provides stronger incentives for charge management and the participation in ancillary services, which will be discussed in more detail below.²²

Intertemporal Factors in Dispatch

The flexibility offered by electric bus systems in terms of the configuration of the assets (vehicle and infrastructure), geolocation of loads (sites where the charging events take place), and load control (the ability to vary the instantaneous power demand for economic benefit, also referred to as smart charging arrangements), creates opportunities to support the economic efficiency of grid operations. The economic analysis, however, becomes more complex. Understanding the potential²³ economics of systems with flexible daily schedules of power demand, such as electric fleet systems, requires consideration of *intertemporal dispatch* optimization. In essence, this means that a controllable load can be leveraged to find revenue streams that will ultimately reduce the operating costs of the systems.

Intertemporal dispatch refers to the dispatch of generators taking into account time-dependent factors. To describe the concepts, it may be helpful to use an example. In its most basic form, the system operator dispatches generators in order, according to their marginal production cost, up to the point where all power demand at that point in time is met. Suppose that there are just two generators available, G_1 and G_2 , with capacities 500 MW and 100 MW, and variable costs $B/.20/\text{MWh}$ and $B/.50/\text{MWh}$, respectively. If at a given time the demand is, for example, 502 MW, the operator would have to dispatch G_1 as well as the costlier G_2 , to meet that demand. If a bus operator had 2 MW worth of controllable load that could be deferred, that could help bring system demand temporarily down to 500 MW, enabling the system operator to meet system demand with only the

²⁰ <http://www.cnd.com.pa/participantes.php>

²¹ Using a simple example, if an operator installs in their depot a charger rated at 100 kW, but in a given month the average maximum power withdrawn from this equipment is 85 kW, then the demand charge is based on the latter.

²² The ability to seek this type of efficiencies depends also on the technical specifications of the charging equipment and whether it can be controlled to modulate the instantaneous power it draws from the grid.

²³ The reader is reminded that some of the discussions about the value of electric bus systems refer to potential value, in the sense that it may not be realizable in the present in Panama for any circumstance, such as the limitations in markets for ancillary services.

lower-cost G_1 , thus generating system-wide savings, on which the bus operator can capitalize. In this example, to account for the availability of flexible loads, the system operator needs to include *intertemporal* factors in the optimization of unit dispatch.

Another case of intertemporal factor is that of startup costs. Building upon the last example, assume that G_2 is a thermal generator that had a startup cost, like generating steam. Once the system operator commits G_2 , this fixed cost will be incurred and will be added to variable cost associated to this generator. In this example, committing G_2 has a double impact on the cost of power. If a bus operator was able to defer the coming inline of the electric bus loads, it would be providing a service to the grid and the public. The value of this service can be quantified, and the bus operator can capitalize on it.

While complex to model and project, this ability of electric buses to dynamically participate in the power markets ought to be integrated into the valuation of these assets. Notice that the degree of modernization of the grid and the related regulatory framework will also influence the extent to which these value streams can actually be materialized by the bus operator. Therefore, the economics of battery electric bus systems also depends on government action to update the pertinent regulatory frameworks.

Long-term contracts and impact on electricity prices

There is increasing interest among power generators in Panama to enter into long-term contracts with large users for the sale of electricity. It is well known that such contracts offer the potential to achieve higher utilization rates for operators' existing and future generation capacity. In return, operators are ready to negotiate lower electricity rates. Another important benefit of long-term contracts is that they may serve as a hedge against the price risk that operators face when they participate in wholesale markets.

The long-term purchase contract is an instrument with great potential for electric bus fleets to reduce operating cash flows, while hedging themselves from risks derived from volatile generation costs. The ability of bus fleets to enter in long-term contracts and the terms that they are able to negotiate will depend on their demand for kilowatt-hours and power. This induces a relationship between rates and scale of the fleet. The results of the analysis will confirm the potential that these instruments have to create sustainable investments in clean transportation.

Nodal and Regional Pricing

Trends of grid modernization point to operations where loads can be flexibly responsive to wholesale prices. In some markets, generators face nodal prices, while loads face regional prices. This difference leads to inefficiencies whenever loads cannot adjust their consumption according to the right generation price signal. Electric bus operators would ideally like to have accurate information, to implement smart charging strategies that increase the likelihood of charging when wholesale prices are lower and, conversely, decrease the likelihood of charging when wholesale prices are higher. Similarly, regional

pricing impairs the ability to make efficient investments, as it may lead to over investment in areas with higher nodal prices and to underinvestment in areas with lower nodal prices.

Electric Bus Systems and Grid Services

The integration of electric bus systems and the grid, in this report, refers to technological and economic processes that increase the economic and environmental value of electric buses, while maintaining electricity system operability, maximizing the added efficiency and resiliency to the grid. In the context of the current trends of grid modernization and the design of efficient electric bus systems that are really integrated with the grid, the availability of price signals to which grid assets can respond is critical. Price signals would enable electric bus systems to interact with the grid in ways that create value for both systems. Price signals are generally provided by the system operator via a market for *ancillary services*.

To date, the only price signal available in Panama in the medium-high voltage electricity retail side is a system of tariffs that provides incentives for shifting consumption from peak hours to off-peak hours. Ancillary services markets are not yet developed in Panama, and thus there are limited data for the analysis of cash flows that could be derived from the participation of electric bus systems in such markets. This analysis is included regardless, to provide Panama with a preliminary understanding of the role of ancillary markets in the integration of electric bus systems.

The design of ancillary markets varies across system operator boundaries. In the United States, Order No. 888 of the Federal Energy Regulatory Commission (FERC) defined five ancillary services, namely:

- Scheduling, system control and dispatch;
- Reactive supply and voltage control from generation service;
- Regulation and frequency response service;
- Energy imbalance service; operating reserve—synchronized reserve service; and
- Operating reserve—supplemental reserve service.

Order No. 890 later added the *generator imbalance* ancillary services.

In addition to the geo-administrative variation of ancillary markets, there are ongoing deliberations about the need to modernize ancillary markets to reflect the structural transformation of the grid, predominantly characterized by advanced information technologies, the increasing penetration of variable-generation assets, and the proliferation of assets on the grid edge such as electric vehicles. Ancillary markets need to modernize, to support innovation and decarbonization, while maintaining grid stability.²⁴

²⁴ Energy UK (2017) Ancillary Services Report 2017. Available on the web at <https://www.energy-uk.org.uk/publication.html?task=file.download&id=6138>

Because of their energy limitations and lifecycle degradation, battery systems are specially poised to provide frequency response services.²⁵ For this analysis, frequency regulation and frequency response services will be considered, as representative of the potential economic and financial effects of market-based integration of electric bus operations with the grid. Frequency is affected by differences between power supply and load demand, and as such, it is one of the key metrics of stability of an interconnected system. The system operator is required to take action — frequency response — to maintain frequency close to statutory limits (60 Hz in Panama).²⁶

Frequency response is delivered by the combined action of *synchronous inertia*, *primary frequency response*, and *secondary frequency response*. Synchronous inertia the frequency correction typically delivered by synchronous generators via electromechanical coupling.²⁷ Current trends in the generation mix, in Panama as well as globally, are toward decreasing the share of synchronous generators, such as coal-fired power plants, and increasing the share of non-synchronous generators, such as wind farms.²⁸ This is resulting in decreasing availability of synchronous inertia, and ultimately shifting some of the responsibility for frequency corrections to primary frequency response.

Primary frequency response service can be defined as “a resource standing by to provide autonomous, pre-programmed changes in output to rapidly arrest large changes in frequency until dispatched resources can take over.”²⁹ In plain language, a resource provides primary frequency response service when it is programmed to react fast (within seconds) automatically to deviations in system frequency beyond a prespecified level, to help restore the balance between generation output and load demand. Synchronous generators can provide primary frequency response services with controls that increase (reduce) output when system frequency is under (over) the statutory level. However, synchronous generators face disincentives to provide this service and available capacity has been declining. Legacy wind and solar systems are not able to provide primary frequency response, although power electronics installed in new wind and solar developments is changing this to some extent.^{30,31} It should be noted that for wind and solar to provide primary frequency response, either in under- or over-frequency events, they

²⁵ He, G., Q. Chen, C. Kang, P. Pinzon, and Q. Xia (2015) Optimal bidding strategy of battery storage in power markets considering performance-based regulations and battery cycle life. *IEEE Trans. Smart Grid*.

²⁶ While system frequency is 60 Hz in Panama and other countries such as Costa Rica, Colombia, and the United States, for the majority of the countries this frequency is 50 Hz. Examples of countries with system frequency of 50 Hz include Australia, Argentina, Chile, and Great Britain.

²⁷ Synchronous generators have rotational inertia that is proportional to (synchronized with) the frequency of the system to which they are connected. An important characteristic of these generators is thus that their rotational inertia responds in a corrective fashion to variations in frequency.

²⁸ Unlike synchronous generators, non-synchronous generators have speed that is not proportional to the frequency of the system, and therefore there are not readily equipped to deliver frequency correction.

²⁹ FERC Order No 819. 153 FERC ¶ 61,220.

³⁰ Power electronics in smart inverters can give solar systems the capability to provide primary frequency response for a short period of time after the event. Power electronics controllers can vary the pitch of wind turbine blades and control the power output to some extent.

³¹ PJM Interconnection (2017) *PJM's Evolving Resource Mix and System Reliability*.

have to operate under capacity, which carries an energy and environmental opportunity cost.

Using about 1.5 million data points from National Grid, in the United Kingdom, second-by-second system frequency deviations are shown in Figure 3, for the first half of the month of January, for the years 2015 and 2018. While a detailed data analysis is outside the scope of this report, these visualizations serve to suggest that frequency deviations are larger in more recent periods.



Figure 3. Frequency deviations for the first two weeks in the month of January in the years 2015 (bottom) and 2018 (top), in the National Grid system (Data source: National Grid)

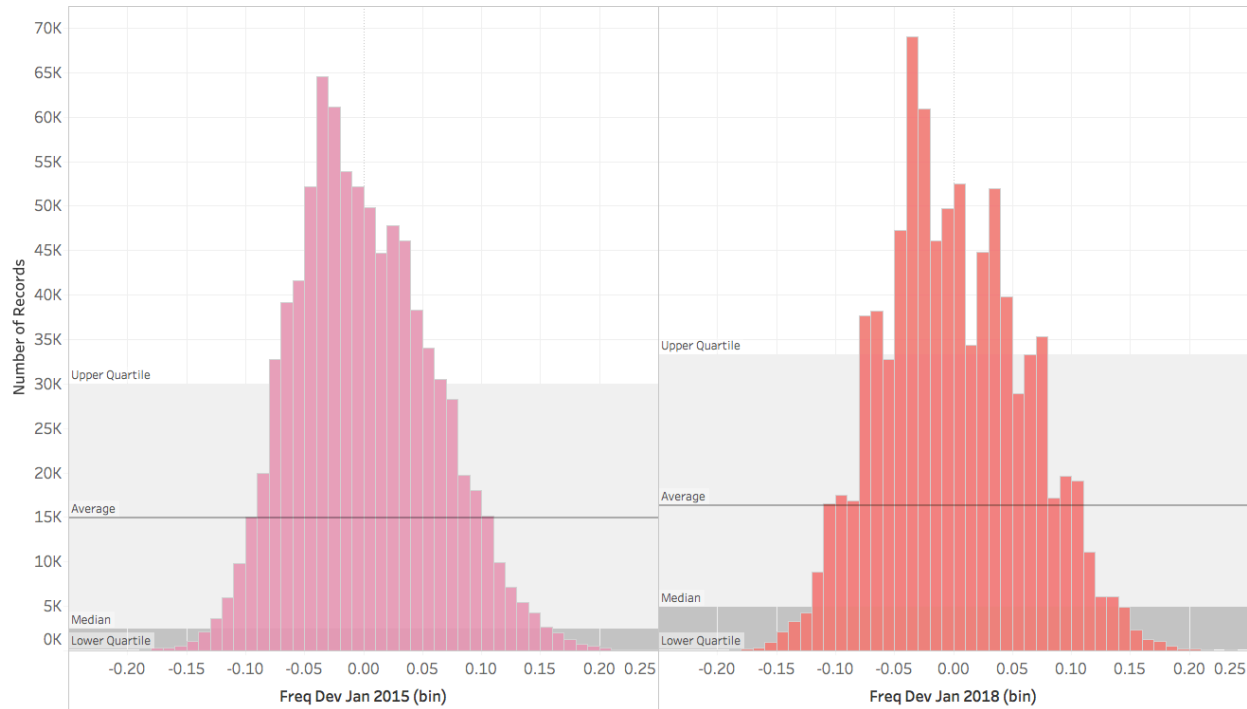


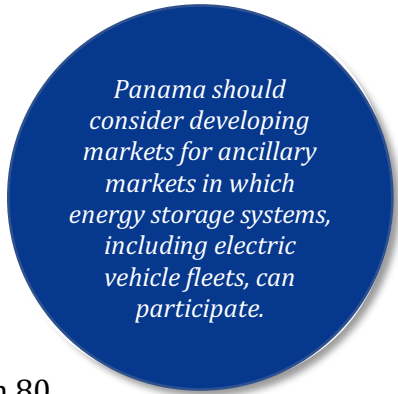
Figure 4. Histograms of frequency deviations for the first two weeks in the month of January in the years 2015 (left) and 2018 (right) in the National Grid system (Data source: National Grid)

Frequency response services are typically categorized in terms of the speed of the response to the event that needs correction, and the duration of the service provided toward the correction. To illustrate this point, National Grid defines the following categories:

- *Primary response*: The response happens within 10 seconds of the start of the event, and is sustained for 20 seconds;
- *Secondary response*: The response happens within 30 seconds of the start of the event, and is sustained for 30 minutes;
- *High-frequency response*: The response happens within 10 seconds of the start of the event, and is sustained indefinitely;
- *Enhanced frequency response*: Response to events within 10 seconds, to be sustained indefinitely.

Enhanced frequency response (EFR) is a newer dynamic service aimed at maintaining system frequency within statutory levels prior to fault. Not all regulation signals are structurally identical. Even though they seem random, they do carry information that can be used for the more efficient utilization of the battery and conventional resources providing regulation services. Signals with faster fluctuations can draw more benefit from battery systems than signals with slower fluctuations.^{32, 33}

Energy storage systems such as batteries, and by extension electric bus fleets, are capable of providing frequency response services at high speed and are thus particularly well suited for EFR.³⁴ An important distinction is that energy storage systems can typically provide grid services by regulating the rate and direction of the energy flow, while onboard battery systems can regulate their rate of charge but cannot, presently, discharge to the grid. Studies have shown that energy storage systems can respond within 80 milliseconds of events of frequency deviation beyond the established threshold, or *deadband* (for example, $\pm 0.05\text{Hz}$).³⁵ These services are typically secured via monthly tenders, although these are progressing to weekly tenders with fast-response products. The general direction for modern grid operations is to advance toward near-real-time markets/auctions, probably combined with long-term tenders, to leverage new investments in flexible assets, such as storage systems (including transportation systems).



Panama should consider developing markets for ancillary markets in which energy storage systems, including electric vehicle fleets, can participate.

As stated above, Panama does not have a market of this type at the moment, and therefore there are no local data that could be used to make quantitative estimates of their potential impact. Panama should consider developing markets for ancillary markets in which energy storage systems, including electric vehicle fleets, can participate. This should include the design of market elements that recognize the fast response, limited energy, high accuracy that characterize energy storage systems. To cite an example, FERC requires transmission providers to account for these characteristics in their determination of the resources that provide regulation and frequency response service.³⁶

One way in which the FERC requirements have been implemented is by using a so-called dynamic control signal (RegD) and a slower signal (RegA). Filtering the area control error (ACE) signal, RegD is the high-pass frequency while RegA is the low-pass frequency. RegD

³² A filtering strategy can be used to divide the regulation signal into a part for batteries and a part for synchronous generators.

³³ Leitermann, Olivia (2012) *Energy Storage for Frequency Regulation on the Electric Grid*. Doctoral Dissertation, Massachusetts Institute of Technology.

³⁴ Delille, G., B. Francois, and G. Malarange (2012). Dynamic Frequency Control Support by Energy Storage to Reduce the Impact of Wind and Solar Generation on Isolated Power System's Inertia. *IEEE Transactions on Sustainable Energy*, **3** (4): 931-939.

³⁵ Greenwood, D.M., K.Y. Lim, C. Patsios, P.F. Lyons, Y.S. Lim, and P.C. Taylor (2017). Frequency response services designed for energy storage. *Applied Energy* **203**: 115-127.

³⁶ FERC Order 755. 137 FERC ¶ 61,064. and FERC Order 784. 144 FERC ¶ 61,056.

is the signal designed to account for the special attributed of energy storage systems that were just described.³⁷ Resources submit bids with a capability component (amount of regulating capability) and a performance component (the ability to follow the regulation signal). The system operator then arrives at Regulation Market Capability Clearing Price (RMCCP, in \$/MW) and a Regulation Market Performance Clearing Price (RMPCP, in \$/MW) for every hour.³⁸ Figure 5 shows historical hourly values for RMCCP and RMPCP over the period January 1, 2014 to December 31, 2018 (about 44,000 data points).

The regulation clearing price credit is calculated as:

Regulation clearing price credit = Regulation RMCCP credit + Regulation RMPCP credit,³⁹

Where:

RMCCP credit = (Regulation MW x RMCCP x PerfScore)

RMPCP credit = (Regulation MW x RMPCP x Mileage Ratio x PerfScore)⁴⁰

As seen, the credit received by a participating resource is also proportional to its available capability and its performance. The Mileage Ratio is continuously varying but a typical value could be around 3. PerfScore is a performance score calculated based on the resources accuracy, delay, and precision in following the control signal. Battery systems have performance scores in the order of 93% to 98%,⁴¹ significantly better than steam, hydro, and demand-side resources.⁴² Figure 6 shows price credits for a hypothetical resource composed of one representative electric bus, using an available capacity of 0.1 MW and a performance score of 95%.

³⁷ PJM Interconnection (2017) *PJM Manual 11: Energy & Ancillary Services. Market Operations*. Revision 87.

³⁸ Ibid.

³⁹ PJM (2019) PJM Manuals, Sec. 4 Regulation Accounting. Accessed at <https://www.pjm.com/directory/manuals/m28/index.html#Sections/42%20Regulation%20Credits.html> on July 2019.

⁴⁰ The Mileage Ratio is a measure of the movement of Regulation D resources relative to Regulation A resources. Mileage is the “distance” in terms of megawatts that the resource follows in response to the control signal within the period. The mileage of resources following a dynamic signal (Regulation D) is much higher than that of resources following a conventional signal (Regulation A), and thus the Mileage Ratio is bigger than 1.

⁴¹ Customized Energy Solutions (2014) *PJM Frequency Regulation—Price Forecast and Financial Analysis*. Reported in Avendano-Mora, M. and Camm, E.H. (2015) Financial assessment of battery energy storage systems for frequency regulation service. *IEEE Power & Energy Society General Meeting*.

⁴² PJM (2014) *Performance-based Regulation Market in PJM*. Presentation to the New Jersey Storage Working Group.

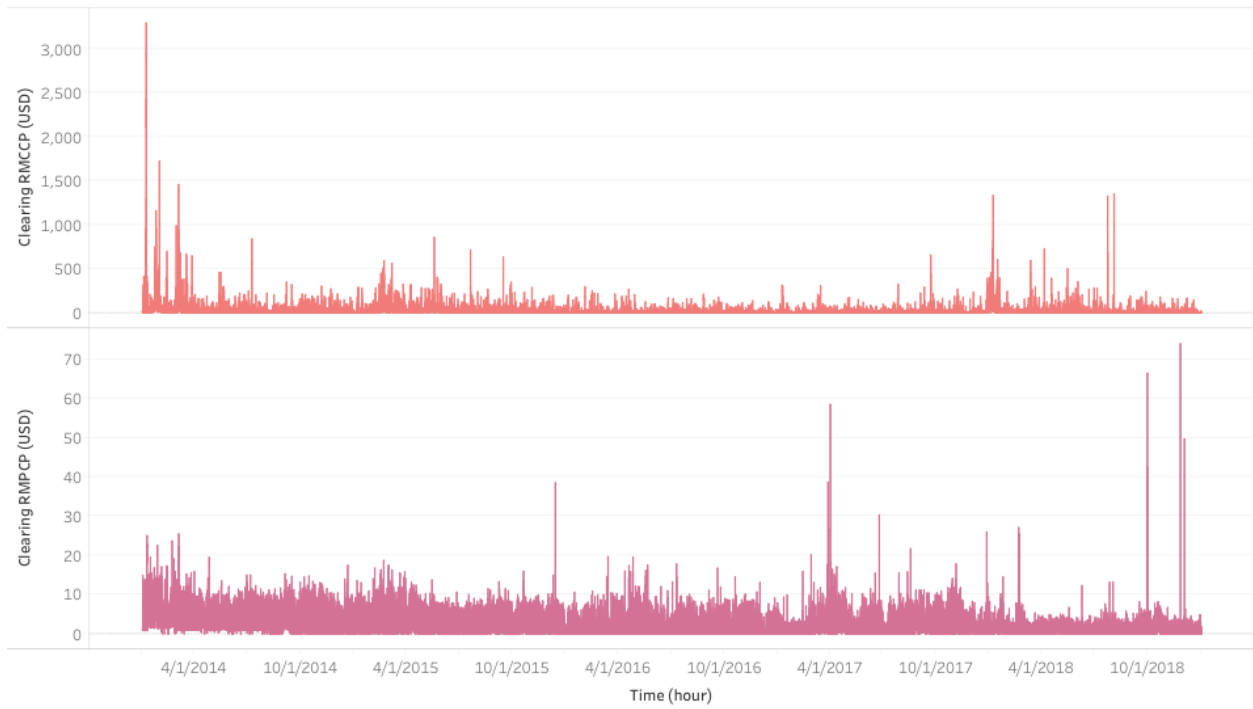


Figure 5. Five-year historical of clearing prices of Regulation Market Capability and Regulation Market Performance for PJM. Data source: PJM.

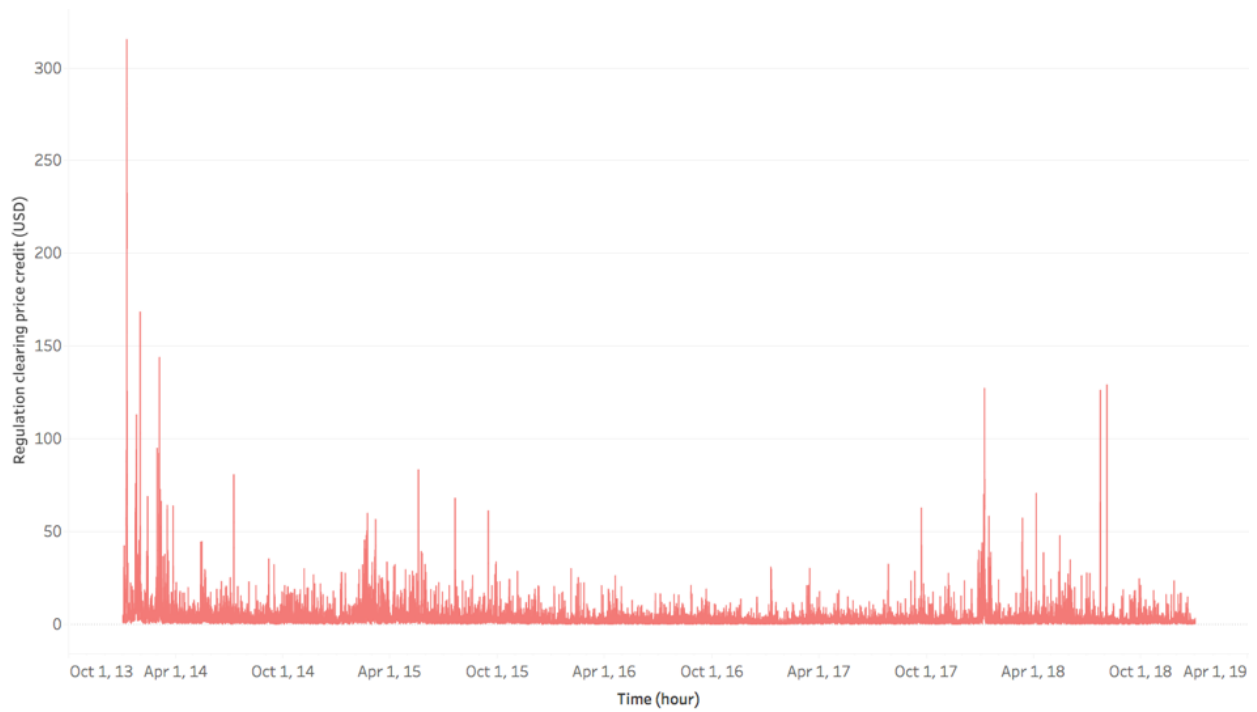
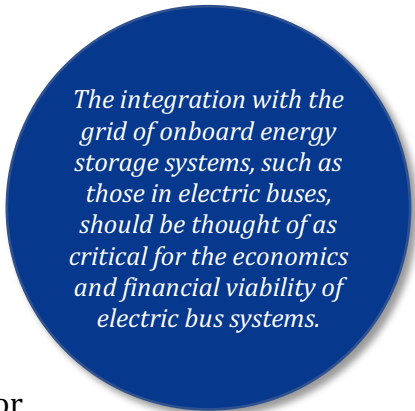


Figure 6. Five-year historical clearing price credits for regulation services in PJM, for the case of one representative electric bus. (Data source: PJM).

As visualized in Figure 6, regulation clearing price credits (as well as the underlying RMCCP and RMPCP) are volatile and have a white noise-like appearance. We find that price credits seemingly follow a lognormal distribution (Figure 57 in Appendix 1). This is important because it suggests that credit prices may be modeled as a stochastic process using the methodologies described later in the report. Empirical evidence shows that regulation prices decline as the market matures.⁴³ Thus, in addition to their probabilistic distribution, the expectation for credit prices is to exhibit a downward trend toward a long-term equilibrium level.

It is emphasized that the integration of energy storage systems with the electric grid is not merely a theoretical possibility, but a developing reality with tangible and important implications for the economics and the sustainability of modern electric grids. By extension, the integration with the grid of *onboard* energy storage systems, such as those in electric buses, should be thought of as critical for the economics and financial viability of vehicle-infrastructure-grid systems. To aid in visualizing this reality, Figure 7 uses data from National Grid for the month of July, 2018, to illustrate the different types of resources that offer frequency response services, focusing in the case of primary response. The size of the bubbles represents the duration of availability, on a scale of 0 to 24 hours. It can be seen that battery systems are active participants in the frequency response ancillary market across the spectrum of capacity and prices. Using the same dataset, Figure 8 shows a cost curve for frequency response services developed using the same dataset.



The integration with the grid of onboard energy storage systems, such as those in electric buses, should be thought of as critical for the economics and financial viability of electric bus systems.

⁴³ Customized Energy Solutions (2016) *Energy Storage Market Current State and Trends*. Presentation to 2016 National Summit on Renewable Portfolio Standards.

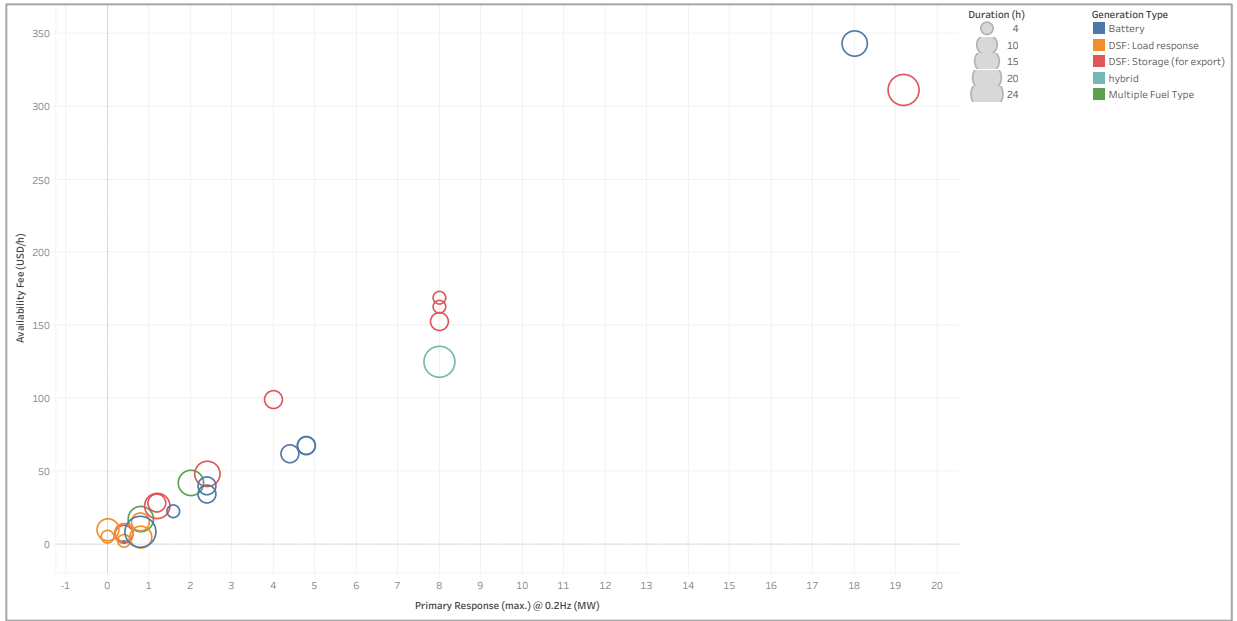


Figure 7. Sample data of accepted availability fee, capacity available, and asset type for primary frequency response services in the National Grid territory (Data source: National Grid)

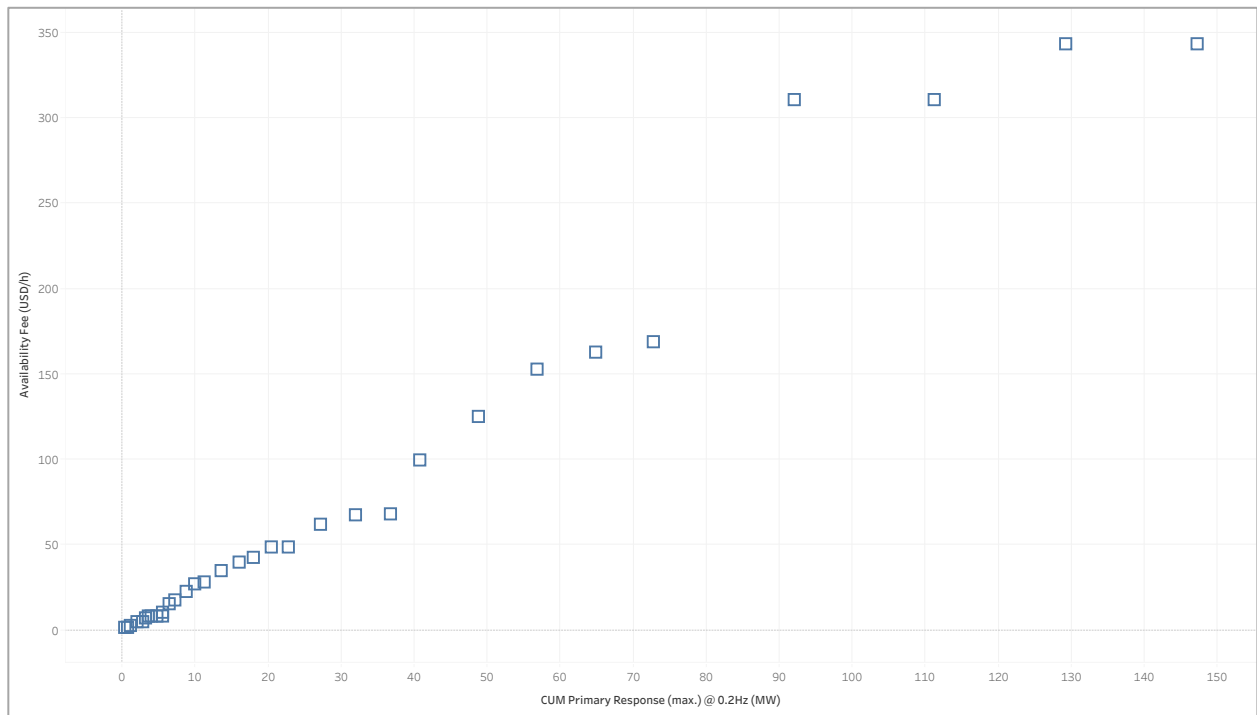


Figure 8. Cost curve for frequency response services for one monthly period in the National Grid territory (Data source: National Grid)

Ancillary Services and Electric Bus Charging Strategy

The participation in ancillary services markets can be integrated into an optimization process to design a charging strategy that maximizes value to the electric bus system. In a nutshell, this notion means the following:

1. Given that the efficient configuration of an electric bus to serve a given route has been determined via technical analysis (as done in an earlier part of this technical assistance), and
2. Given that this electric bus can be used as a resource to provide services to the grid, such as frequency response (via the establishment of modern ancillary markets),
3. Then an optimal combination of charging management strategy *and* charging equipment configuration can be defined, that minimizes capital outlays for infrastructure and maximizes revenues from ancillary services, while maintaining the required level of service.

To understand the economic meaning of ancillary services like frequency response from the perspective of electric bus systems, the following factors should be noted:

- a. Market design: Ancillary services contribute to cash flows, contingent on the existence and regulatory structure of a market for ancillary services;
- b. Demand for services will increase: Contribution to cash flows will depend on the patterns of generation, demand, and operation. As discussed above, the increasing penetration of renewable variable sources of power and the decrease in system inertia will be accompanied by an increase in frequency deviation events, and ultimately lead to a steady *increase in demand for frequency services*.
- c. Battery systems will have a role: As discussed, energy storage systems are particularly adept at responding very fast to frequency deviation events and will play a significant role in the provision of ancillary services. If well planned, electric bus systems have the potential to help electric utilities defer investments in storage systems.
- d. The role of V2G is yet uncertain: No consideration is given in this analysis to rountrip vehicle-to-grid power flows. Instead, the focus is on charging management as a means to increase and decrease demand.
- e. Any bus system configuration can participate: Participation in ancillary services markets is not exclusive to systems designed for overnight charging.

5. Asset Valuation Methodology

The mainstream analysis of economics of vehicle technologies has taken an approach known as *lifecycle cost of ownership* (LCO) or *total cost of ownership* (TCO). While this approach can be helpful for established technologies where technology systems are fairly determined, it is not the best approach whenever new technology systems are involved. Instead, an asset valuation approach can capture the system risks and revenue stream opportunities, and offer a more meaningful platform for decision-making.

While electric buses still imply higher initial capital expenditures, they create opportunities for lower operating and maintenance costs and systems integration. The latter are dynamic in nature, as they depend on evolving regulatory and technology frameworks. With regards to operating costs, it is widely accepted that, on a per-kilometer basis, the cost of electricity fuel can be lower than the cost of conventional fuels, because of the higher efficiencies of the electric drivetrain relative to internal combustion powertrains. As clearly laid out in the technology evaluation section, this competitive advantage will hold depending on the operation conditions and the appropriate design of the technology system to serve a given route. We will analyze in this section how, and to what extent, this technology efficiency advantage can be translated into economic/financial advantage in the case of Panama City.

Another important competitive advantage of electricity as a fuel, generally unaccounted for in economic analyses, is that of risk hedging. As a commodity, the prices of petroleum fuels are exposed to the volatility in those markets. Electricity markets, on the other hand, are local, enable more predictable cost projections, and, importantly, offer (depending on regulatory and market structures) opportunities for assets to participate in the market.

Accounting for the stochastic (uncertain) nature of petroleum prices is an important step in the economic/financial assessment of bus technologies for several reasons. It highlights that the bus technology is embedded into a broader techno-economic system, and it cannot be thought of in isolation. Considering the bus and the fuel as a system helps unveiling more explicitly the risks inherent to it. This allows new, more risky technologies, such as battery electric bus systems, to compete on a more leveled playing field from this perspective. In particular, studies taking a TCO approach have consistently used single “representative” point value for the price of fuel. This exclusion from the analysis of the cost of price-bound uncertainties is inconsistent with standard practices in investment analysis in the energy sector, and it renders the whatever results are obtained unreliable. Not only is the future price of fuel uncertain, but the uncertainty tends to increase over time, as the probability density distribution flattens and spreads, and its mean changes as a function of time.

Real-Options Analysis

Investment processes that can imply decision steps along the way can be analyzed using a real-options framework, and capture some factors that are not captured by conventional discounted cash flow analysis, including the value of flexibility in management decisions.

Typical applications of real-options analysis include natural resources development, energy generation investments, research and development investments, corporate valuation, and others. Investments in new-technology bus systems can be seen as multi-step decision making process, whereby progressively large investments are considered in light of pertinent risks and uncertainties, as well as the comparative value of competing technologies, toward an eventual final decision of an investment at scale. In general terms, the value of an investment can exceed the value calculated as a traditional discounted cash flow (DCF), because of the sponsors' options to earn revenues through increased flexibility in decision making.

The existence of, and adequate accounting for, real options, can turn an investment that is initially unattractive into an attractive one. A common type of option in the analysis of projects is the *expansion option*, also known as *growth option*. In our case, an expansion option would represent the situation in which, at a later point in time (i.e. after the project has started), additional capital is committed to scale it up, for example procuring more buses and supporting infrastructure. With the initial deployment of assets, Panama will start learning, mitigate uncertainties, and acquire valuable new information about the operations of the bus systems, the ability of infrastructure to support expansions, evolving regulatory frameworks, and other factors. The value of such option can be calculated as the difference between the discounted worth of the investment with the option and that without the option.

The economic and financial sustainability of investments in electric buses, more than for their diesel and CNG counterparts, is affected by scale and the schedule of fleet transition (investment timing). The underlying asset would be the technology system including a portfolio of N bus units with a set T_B of technical characteristics, and supporting infrastructure with a set T_I of technical characteristics. The present value of the capital cost is the price to exercise the option to invest.

Without attempting a thorough treatment of the real-options methodology, a general description is presented to help all readers follow through the following sections. The investment valuation starts by quantifying the uncertainties, defining potential states of the future. As it will be seen, the key sources of uncertainty included in the analysis are the evolution of prices for diesel and electricity. A set of possible states of diesel and electricity prices at the end of the period are modeled using a binomial lattice.⁴⁴ With these prices, the respective diesel and electricity costs and associated cash flows in the nodes of the last time period are calculated. The value of the project is then calculated by backward induction through the price lattice, one month at a time. The value at each node is the discounted sum of net operating cash flow at that node plus the expected value of the

⁴⁴ The mathematics involved in the generation of the lattice tree are not included. Interested readers may consult any from a number of excellent references on the topic, such as Finnerty, J.D. (2007) *Project Financing: Asset-Based Financial Engineering*, John Wiley & Sons, Hoboken; Abadie, L.M. and J.M. Chamorro (2013) *Investment in Energy Assets Under Uncertainty: Numerical Methods in Theory and Practice*. Springer-Verlag, London; Chance, D. and Anderson, P. (2002) *Real Options and Investment Valuation*. The Research Foundation of the Association for Investment Management and Research; and others.

project in the subsequent time step.⁴⁵ This process is continued until the time of project start, to determine its present value (see Figure 9 for an illustration).

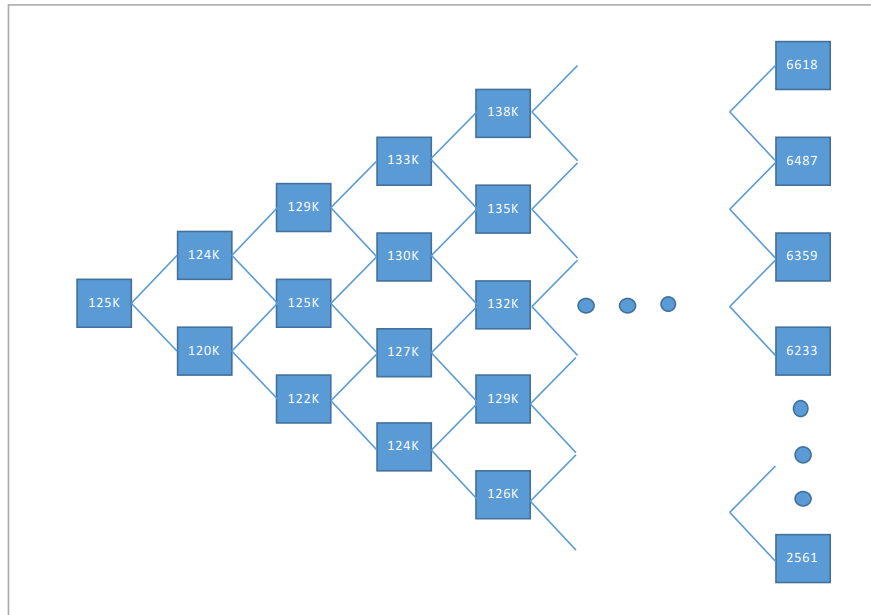


Figure 9. Structure of a binomial lattice, with hypothetical values

The project values at each node in the tree is the discounted value of the future cash flows in the nodes immediately ahead. In practice, these are estimated via one of two methods, namely: a) using options pricing theory, or b) using probability-weighted values discounted with a risk-adjusted factor. In project real options analysis, the latter is more typically utilized. Discount rates are adjusted as needed for perceived risk. Lower rates imply that those who are making the investment decisions have lower perceptions of the risk. In the extreme, using risk-neutral would imply that they are risk neutral.

Weighted Average Cost of Capital

The required rate of return on an investment can be thought of as an opportunity cost. Investors require an expected rate of return equal or larger than what they could obtain in comparable investments. This will hold true whether investors measure returns purely in financial terms or in ESG (environmental, social, and governance) terms. It is known that a higher cost of capital tend to deter capital-intensive investment alternatives, and thus, in the particular case of bus systems, it would favor conventional technologies vis-a-vis new

⁴⁵ Here the risk-free is used because the systematic uncertainty is accounted for via de construction of the binomial lattice.

technologies. For an investment in new-technology bus systems, and particularly in electric bus systems, there are no comparable investment opportunities yet. As the interest in these systems grows, the authors of this report expect a steep increase in competition for capital and, with it, a growth in demand for sound investment plans, including in-depth expert technical and economic evaluation.

When there are no obvious references, the hurdle rate is typically defined in terms of the weighted average cost of capital (*WACC*). The *WACC* can be expressed in terms of the weighted average cost of the components of the financing package. For a package composed of long-term debt and equity, the following relation applies:

$$WACC = (1 - \theta)r_e + \theta(1 - \tau)r_d$$

Here, θ is the debt-to-equity ratio, r_e and r_d are the required returns for equity and debt, respectively, and τ is the marginal income tax rate applicable in Panama to the project's income. Thus, identifying appropriate values for the returns would enable the estimation of the *WACC*.

The risk-free rate of return are typically associated to U.S. government securities. Considering a timeframe of about 10 years, a Long-Term Composite rate at 2.31 is used.⁴⁶ There is great potential in Emerging Markets (EM), such as Panama, to issue green bonds to finance their enormous needs for investment in infrastructure. Green bonds can be a vehicle to attract international investments, particularly for projects of certain scale. It is not clear yet whether the scale of typical fleet investments could limit the potential of a green bond to interest investors, but project aggregation is a possible strategy to attract funding for projects of smaller scale. Transparency and disclosure, as advocated by the Green Bond Principles (GBP), support green bond credibility and will also help attract capital to EMs. External technical evaluation, review, and monitoring of proposed investments are means to increase transparency and foster investor comfort.

Clean transportation, and related areas such as smart grids and renewable energy fall within the eligible Green Project categories. GBP encourage the use of quantitative performance measures (for example, efficiency, greenhouse gas mitigation, etc.) and, whenever possible, monitoring and reporting achieved impacts.⁴⁷ While electric utilities have not been a particularly active issuer of bonds in emerging markets, green bonds are natural instruments to finance infrastructure developments, which can include public transportation electric fleet systems. Searching for points of reference in the bond market, we look at bonds issued by utility companies and groups of green bonds also in the utility segment:⁴⁸

⁴⁶ This was the ET Composite rate on August 1st, 2019. Source: U.S. Department of the Treasury.

⁴⁷ International Capital Market Association (2018) *Green Bond Principles: Voluntary Process Guidelines for Issuing Green Bonds*. June.

⁴⁸ Climate Bonds Initiative and International Finance Corporation (2018) *Green Bond Pricing in the Primary Market: January – June 2018*.

Table 1. Examples of bonds and green bonds issued by utilities

Issuer	Average coupon	Maturity (years)	Deal size (bn)	Currency
Iberdrola	1.25%	8	0.75	USD
TenneT	1.375%	10	0.5	USD
Enel	1.125%	8	1.25	EUR
MidAmerican Energy	3.65%	30	0.7	USD
BBB utilities	1.5%	9-12	0.9	EUR
A utilities	3.97%	30	0.7	USD
A-BBB utilities	1.35%	4-10	0.6	USD

Looking at the Panama context, Fitch Ratings has given ENSA Issuer Default Ratings (IDR) for long-term foreign and local currency of BBB. These ratings are based on a low business risk profile and a moderate regulatory risk profile. ENSA has stable cash flows and low business risk linked to its monopolistic position, with exclusivity on service over a well-defined territory and a permanent concession. Regulatory risk arises from the monthly adjustments to tariffs to account for variations in fuel prices (discussed later), which can in turn impact cash flows. ENSA is also exposed to regulatory risk through the subsidization of electricity, in the form of the Fondo de Estabilización Tarifaria, described above.

The preceding discussions can inform the adoption of a potential coupon for a green bond with 10-12 years maturity (the approximate life of a bus unit) issued by ENSA, to finance an investment in electric bus systems. It should be noted that the coupon values in Table 1 pertain to investment in infrastructure involving more mature technologies. Two scenarios for an investment in electric bus systems could be designed, namely:

- Lower Risk Scenario: In this scenario, a risk mitigation plan is adopted, including the items below.
 - A technology systems evaluation to determine the assets that would most efficiently meet the performance requirements in Panama,
 - An systems economic and financial analysis that incorporates the technology evaluation, to assess investment viability and efficiency, and
 - Steps to follow the Green Bond Principles guidelines, ensuring transparency, etc.
- Higher Risk Scenario: In this scenario, the primary instrument for risk mitigation is a small scale pilot project.

For the Lower Risk Scenario, a coupon of 1.6 % could be adopted, representing the higher end of the yield spread in Table 1 for bonds with comparable maturity. For the Higher Risk Scenario, a coupon of 3.5% could be used, more similar to bonds with 30-year maturity (higher risk).

Returning to the calculation of the *WACC*, assuming a financing package composed exclusively of debt, using a marginal income tax rate of 25%, the *WACC* estimates in Table 2 would be obtained.

Table 2. Scenarios for the estimation of weighted average cost of capital

Scenario	Estimated Coupon	WACC
Lower Risk	1.6%	1.200%
Higher Risk	3.5%	2.625%

6. Stochastic Analysis of Fuel Prices

Figure 10 shows the historical evolution of retail prices for diesel, along with those of gasoline 95 octane and gasoline 91 octane. While diesel prices particularly suffered the effects of the 2008 price spikes, they have been historically at lower levels relative to gasoline. The stabilization of upward price trends on the period 2011-2014 and the subsequent sharp decreases in 2014-2015, have been followed by an upward trend that continues on in the present. The volatility of petroleum fuel prices, due to irregularities and seasonalities, is qualitatively evident from this visualization. The lower chart in the figure shows the month-to-month jumps in diesel prices over this time period. Later, we will obtain quantitative estimates of this volatility. According to information provided by MiBus, they are able to purchase diesel at favorable parity prices. The public transport company utilizes no strategy to hedge itself against fuel price risk.

Because there is no established market for compressed natural gas (CNG) in Panama, historical data on prices is not available. Instead, historical data on exports of liquefied natural gas from the United States were used, and adjusted to incorporate costs of transport and regasification.

To understand the future cash flows derived from the procurement of diesel to fuel buses, projections of fuel prices over the expected useful life to the vehicles are needed. Because of the uncertainties involved, such projections are approached as stochastic processes. Often, analyses of the expected cost of operation of vehicles have used a single value to represent the future price of fuel. The utter inadequacy of such approach should be apparent from even a casual inspection of Figure 10. Compounding this error, many analyses have also often adopted a single representative value for the energy efficiency of the vehicles. This technical assistance avoids those limitations. The previous chapter performed thorough data collection, data processing, modeling, and computation, to obtain rigorous estimates of vehicle performance for operating conditions specific to routes in Panama City. This chapter incorporates risk and uncertainty in the economic and financial evaluation of bus asset systems. Stochastic methods to show the effect of risk on the comparative economics of different vehicle platforms, including electric and petroleum were used for the first time by Burke, Collantes, and Miller (2013).⁴⁹

⁴⁹ Burke, A., Collantes, G. Miller, M. and Zhao, Hengbing (2015) Analytic Tool to Support the Implementation of Electric Vehicle Programs. Research Report UCD-ITS-RR-15-08

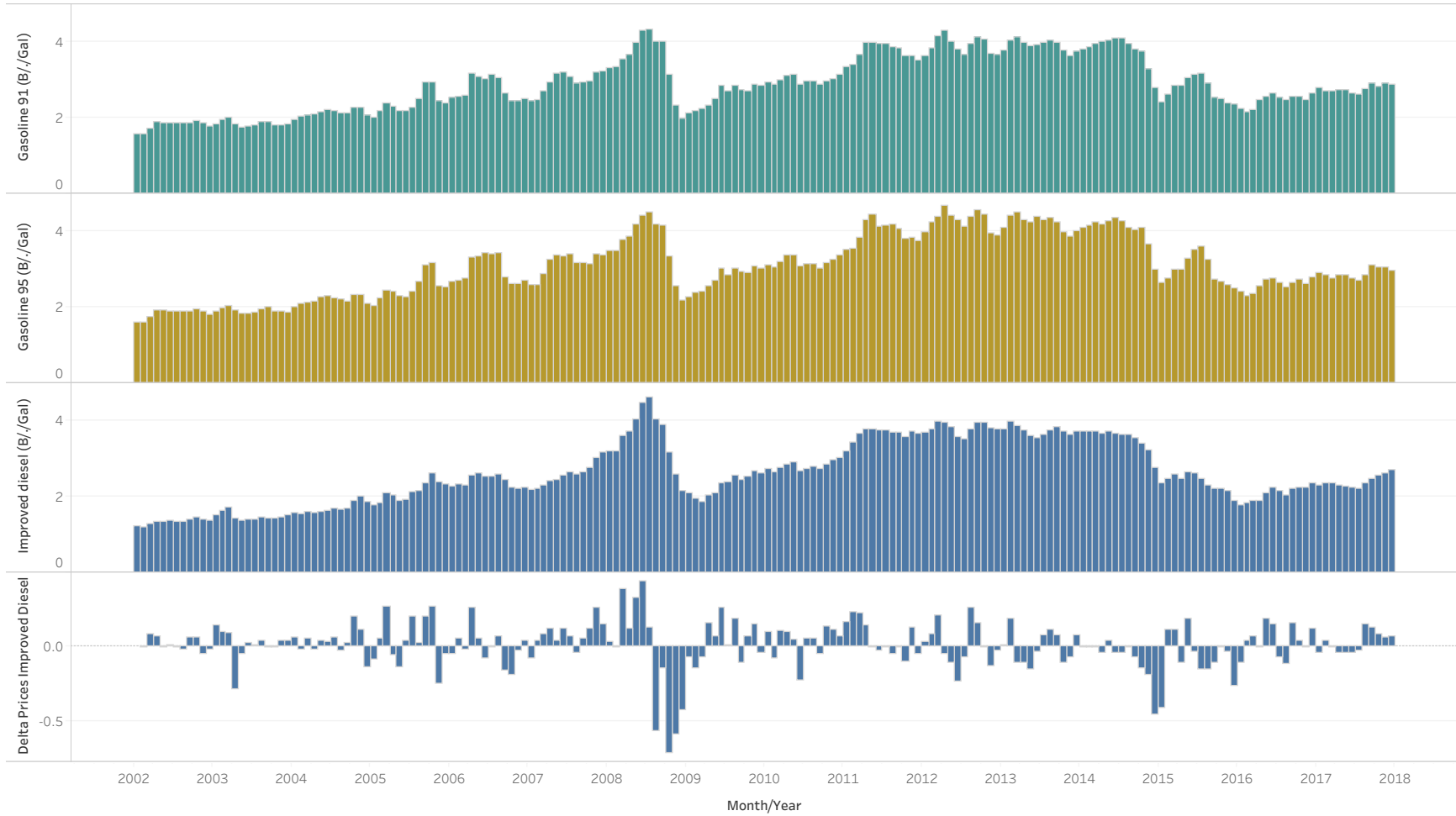


Figure 10. Historical prices of gasoline and diesel in Panama.

What follows is an abridged technical discussion that lays out some of the central principles of the methodology used for the modeling of uncertainty in this report. The modeling of the behavior of the prices of energy commodity is very complex, perhaps a reason why it is not always included in economic analyses. These behaviors are typically analyzed using stochastic modeling that build upon the foundations of Brownian Motion. While exposed to volatility and shocks, prices of energy commodities exhibit a tendency to revert to equilibrium levels in the long-term.⁵⁰ A model that accounts for this tendency is the Ornstein-Uhlenbeck process, that describes the price evolution as the following stochastic process:

$$dS_t = k(S_m - S_t)dt + \sigma S_t dB_t$$

where S_t is the price at time t , S_m is level to which the price tends to revert, and k is a parameter that characterizes the speed of reversion.⁵¹ The instantaneous volatility of the prices is denoted by σ , while dB_t is the increment to a Wiener process.⁵²

Alternatively, commodity prices have been modeled as a Geometric Brownian Motion (GBM), which is a stochastic process that results from the combination of a drift (trend) and a random component (technically, a Wiener process), both of which are proportional to the instantaneous price. Mathematically, and for the purpose of modeling, this is expressed as follows:

$$dS_t = \alpha S_t dt + \sigma S_t dB$$

Here, α is the expected price growth rate (drift), σ is the instantaneous variance of the price (volatility), and dB is a Wiener process whereby $E(dB) = 0$ and $var(dB) = dt$. The GBM has some useful properties, that simplify the analysis relative to mean-reverting processes.⁵³ The appropriateness of using GBM to model energy prices is matter of active discussion among experts.⁵⁴ For the time scales typical of investments in bus fleets, in the order of a decade, studies show that it is adequate to use GBM models. Thus, GBM will be the approach taken for the analyses that follow.⁵⁵

⁵⁰ This phenomenon is often referred to as *mean reversion*.

⁵¹ The parameter k can be estimated as $k = \ln 2 / t_{1/2}$, where the denominator is the expected half-life, or the time it takes the gap between S_t and S_m to halve.

⁵² The Wiener process is characterized by expected value equal to zero ($E[dB_t] = 0$) and variance equal to dt ($var[dB_t] = dt$).

⁵³ Including that the expected growth rate is constant and obtained as $E(dP/P) = a dt$. The instantaneous volatility, sigma, can also be taken as constant, which implies an expectation that the price variability increases with time.

⁵⁴ Abadie, L.M. and J.M. Chamorro (2013) *Investment in Energy Assets Under Uncertainty: Numerical Methods in Theory and Practice*. Springer-Verlag. London.

⁵⁵ For example, Postali, F. and P. Picchetti (2006) Geometric Brownian Motion and structural breaks in oil prices: A quantitative analysis. *Energy Economics* **28**: 506-522.

This technical language may be beyond the appetite of many readers, but it is included here nevertheless for completion, as it summarizes the conceptual foundation of some of the results below. It is not necessary for the reader to dwell in the math; it suffices to gather some general understanding of the concepts that are derived from it. Specifically, the fact that price variability can increase with time is an important, and sometimes underappreciated element in the economic valuation of petroleum-fueled vehicle assets. It indicates that the uncertainty pertaining the price of fuel (and by inference the operation costs) is higher, the longer the expected life of the asset. It will be seen, this uncertainty translates into a higher costs discounted to the present. It is often argued that one of the relative benefits of conventional buses vis-a-vis electric buses is their longer lifecycle. The effect just described of increasing net present operation costs offsets this benefit to a certain extent.

It has then been established that the projection of the prices of petroleum fuels into the future should be treated as a stochastic process and, as such, prices can follow different paths. For any point in time in the future, there should not be an expectation of a single value but a *probabilistic distribution* of values. For the analysis, it is necessary to obtain estimates of these distributions. To this end, Monte Carlo simulations of the GBM process that above described are used. To perform these simulations, estimates of the parameters driving this process, namely the drift (μ) and the volatility (σ) of diesel prices, for the case of Panama, are needed. Using the data on historical monthly parity prices, the drift and the volatility are estimated at 0.0066 and 0.11, respectively. Using for the initial price of diesel the last data point for the historical dataset, the GBM model is used to run many simulations of the progression of this price over a time horizon of 10 years, or 120 months. This timeframe was chosen based on internal procurement practices of Transporte Masivo de Panamá, S.A. (TMPSA, or MiBus), that requires new buses to be active in service, exposed to the local operational and climate conditions, for at least 10 years or 1 million kilometers, whichever occurs first.⁵⁶ Further discussion of vehicle lifetime assumptions is offered later in the report.

Figure 11 illustrates 2,000 such simulations. This figure reveals several qualitative characteristics of these projections. For example, prices show a mild general upward trend (although the more extreme cases in the upper part of the chart may give the visual impression of a steeper trend) and greater dispersion for longer times horizons (reflecting higher uncertainty the further into the future the projections are). Some of the simulation runs exhibit temporary significant dispersion, which represent the unlikely, though possible, events of extreme price levels. The oil price spikes recorded in the year 2008 represent a real example of a rather extreme event.⁵⁷

⁵⁶ This information was provided by MiBus, while representatives of MiBus also indicated that diesel buses in their fleet are typically expected to stay in service for 15 years.

⁵⁷ A certain family of models, known as *jump-diffusion* models, combine Brownian diffusion processes with Poisson-like processes, as an attempt to capture occasional sharp increases in the value of an underlying commodity.

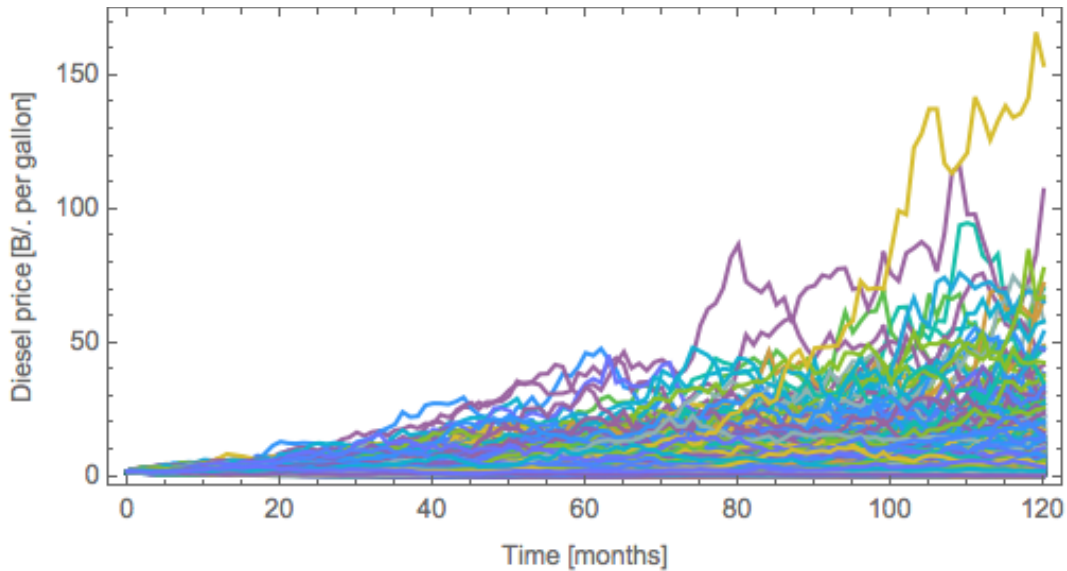


Figure 11. Simulations of the future evolution of the parity prices of diesel following a GBM

Taking cross sections of Figure 11 at various points in time help to show representative probability distributions of the expected prices over the life of the buses. Figure 12 shows these density distributions for 30, 60, and 120 months (33%, 50%, and 100% of the time span considered). This figure shows more clearly what Figure 11 had already suggested, namely that uncertainty about fuel costs is higher for later months in the projections, that their corresponding density distributions have longer tails, and that the means also increase with time, consistent with the upward drift. Notice that values of the price, in the horizontal axis, are shown up to 6. While Figure 11 suggested the possibility of some extreme values, Figure 12 shows that the occurrence of such events has a very low probability.

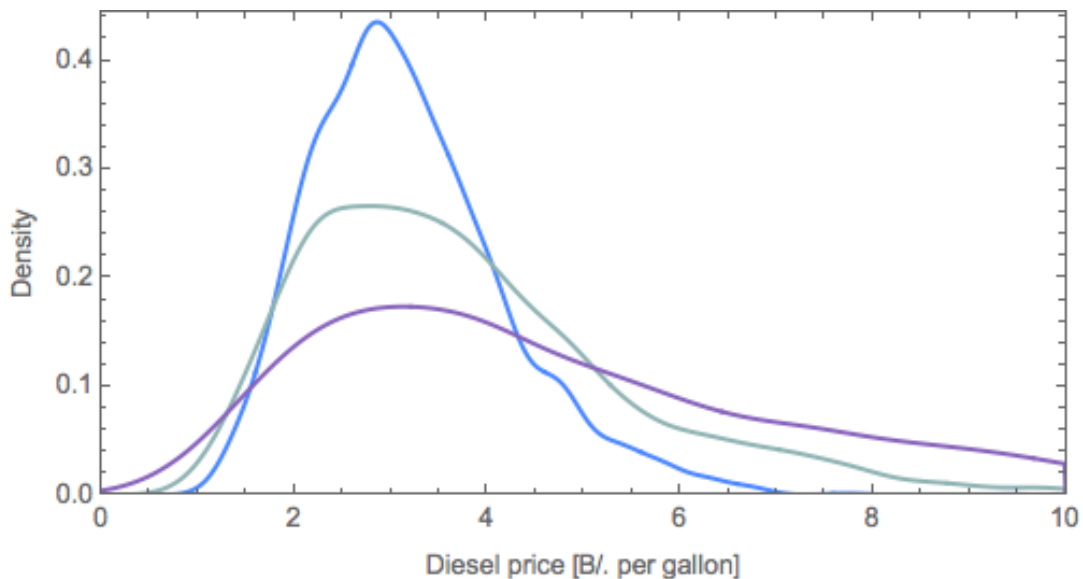


Figure 12. Distributions of diesel log prices at 24, 48, and 96 months, based on GBM simulations

Simulations are similarly produced for the prices of compressed natural gas, and the results are shown in Figure 13. Historical data suggest values drift and volatility for natural gas of 0.0165 and 0.188, respectively.

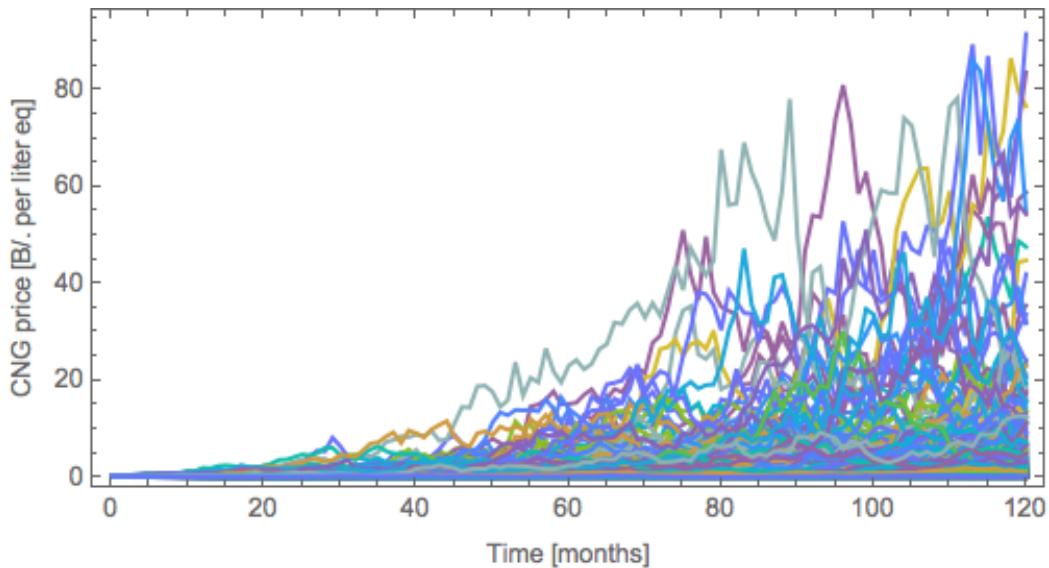


Figure 13. Simulations of the future evolution of the prices of compressed natural gas following a GBM

The spot prices of electricity in Panama, shown in Figure 14, also exhibit significant volatility. This can be attributed in part to Panama's historical dependence on fossil fuels for power generation, as well as seasonal variations of hydropower. As explained above, the regulatory framework dampens the effects that volatility would otherwise have on retail markets, by means of regular adjustments to the retail electricity tariffs. Whether all variations in electricity prices observed in the spot market are internalized by regulatory tariff adjustments and passed onto end users, was not matter of analysis in this report. It is however a question that deserves deeper analysis in a long-term plan for the electrification of transportation in Panama. To the extent that regulations masked underlying market issues (e.g. volatility in the price of electricity), this might create regulatory risks for future investments in fleet electrification.

To analyze the prices of electricity, data was extracted from documents available in the website of Autoridad Nacional de Servicios Públicos, and a database of historical prices for the last 15 years was created. Data for Elekstra Noreste S.A. (ENSA), for medium voltage with demand, or MTD standing for *media tensión con demanda*, and medium voltage hourly, or MTH standing for *media tensión horaria*, shown in Figure 15, are used as representative of the retail prices that an electric bus fleet could face in Panama City. In the context of these values, and considering their respective charging strategies, it is sensible to use off-peak MTH rates for overnight electric buses, and MTD rates for overhead electric buses. The reason for this is that overnight electric buses will benefit from coordinating their charging with times of lower rates in the MTH tariff. Similarly, since overhead electric buses will predominantly charge during peak hours, it would be detrimental to their economics to adopt MTH tariffs, and would be better off within an MTD tariff regime. This

optimization is particularly important as it relates to demand charges. A casual charging strategy that does not account for the impact of demand charges, will certainly affect the efficiency, and might risk the viability of the investment.

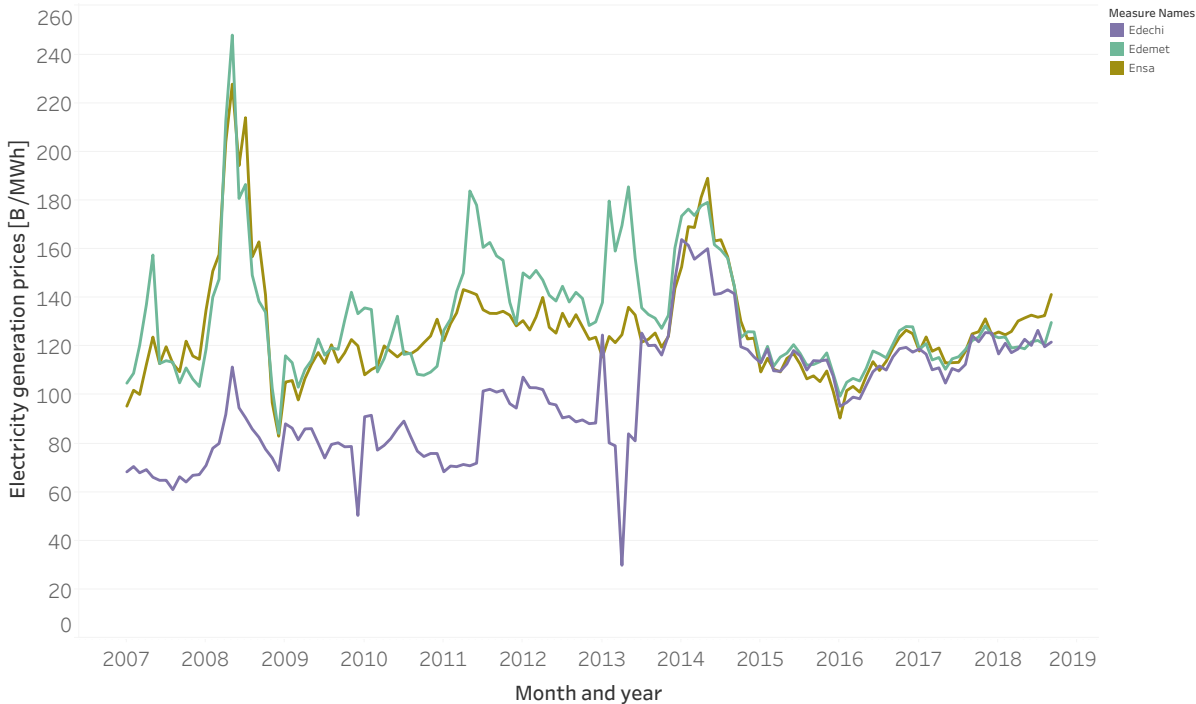


Figure 14. Historical wholesale electricity prices for the three distribution companies in Panama.

It should be noted that there is an increasing number of new generation developments in Panama, with appetite for establishing end-to-end power purchase agreements (PPA). Battery electric bus fleets will be able to leverage these PPA to further position themselves favorably vis-à-vis conventional buses, in terms of operating cost risks. These questions will be discussed in more detail below.

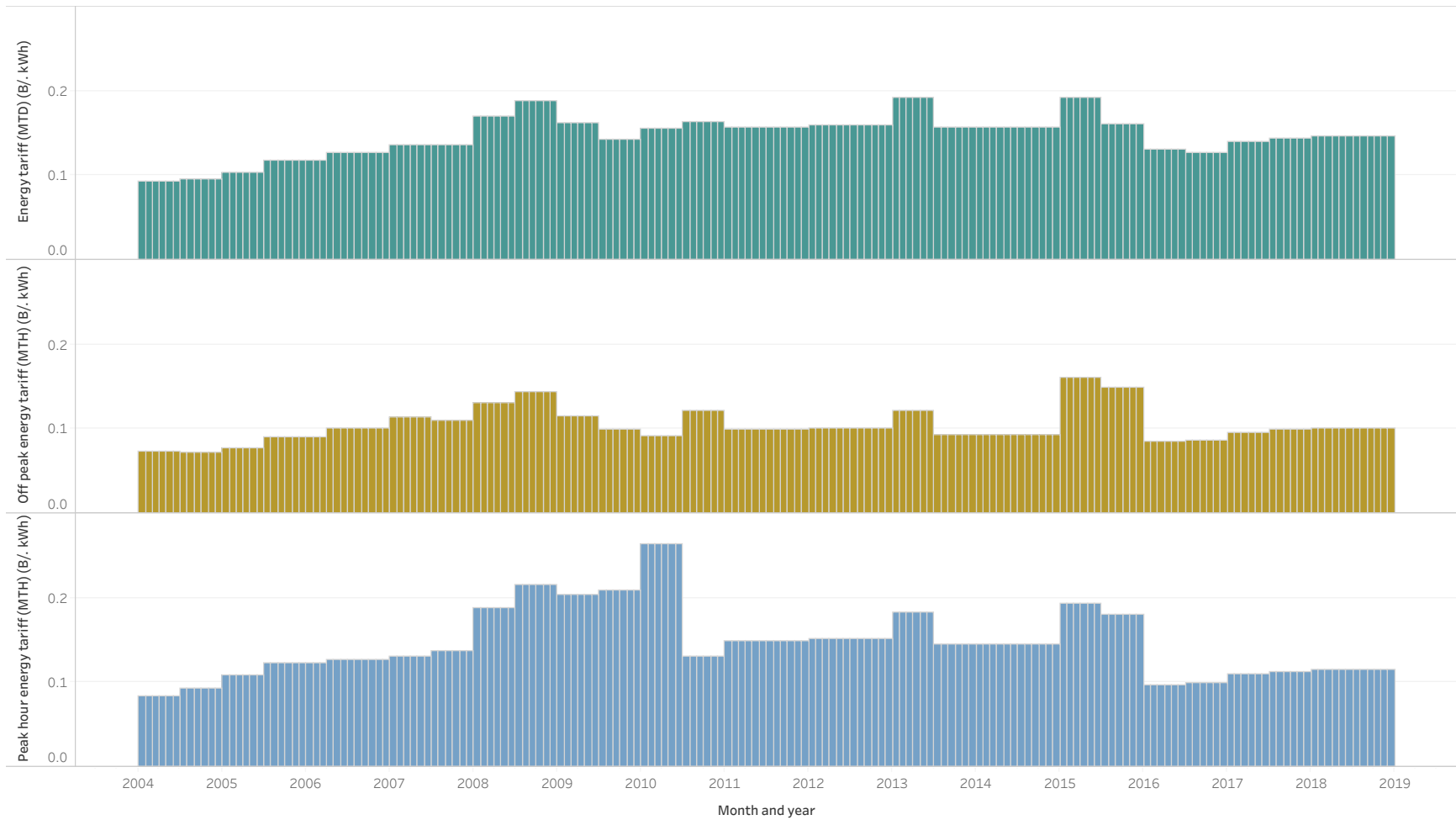


Figure 15. Historical retail electricity tariff in the ENSA service area, MTD and MTH (Data source: Autoridad Nacional de Servicios Públicos)

The database of historical rates can be used to obtain estimates of the parameters of the respective Geometric Brownian Motion processes. Drift and volatility in the MTD tariff are estimated at 0.0035 and 0.0443 for electricity and 0.0022 and 0.0499 for demand charges. These estimates are subsequently used to conduct simulations of the projections of the prices of electricity and demand charges. The simulations for electricity and demand charges for the MTD tariff are shown in Figure 16 and Figure 18, respectively. It is immediately obvious that retail electricity prices are exposed to lower volatility than diesel.

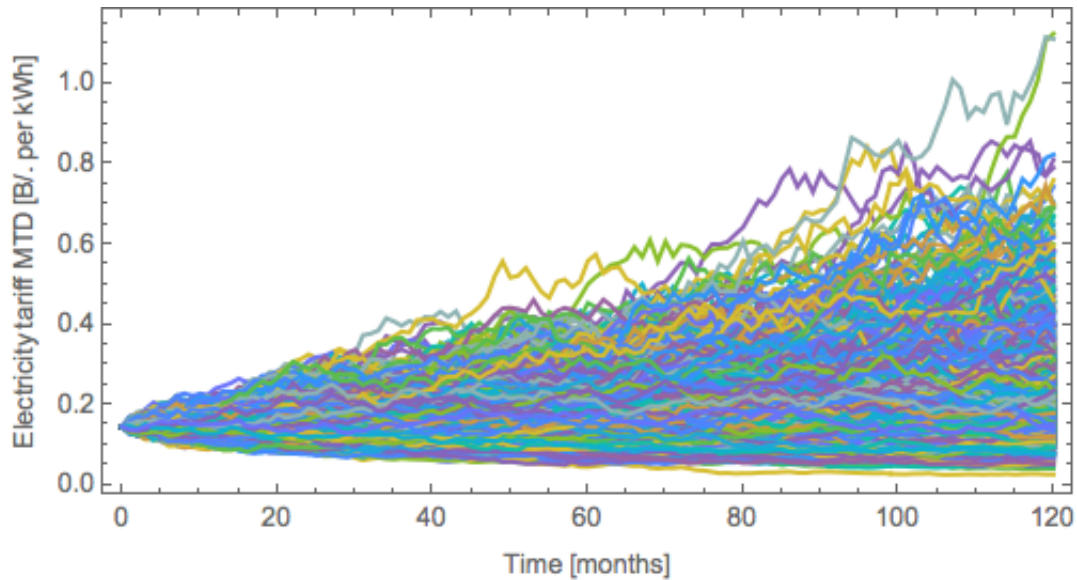


Figure 16. Simulations of the future evolution of electricity rates in the MTD tariff, following a GBM

Figure 17 validates this result, showing the projected probability densities for retail electricity prices at 30, 60, and 120 months. A comparison of this chart with Figure 12 provides evidence of the lower fuel price risk of electric buses relative to diesel buses.

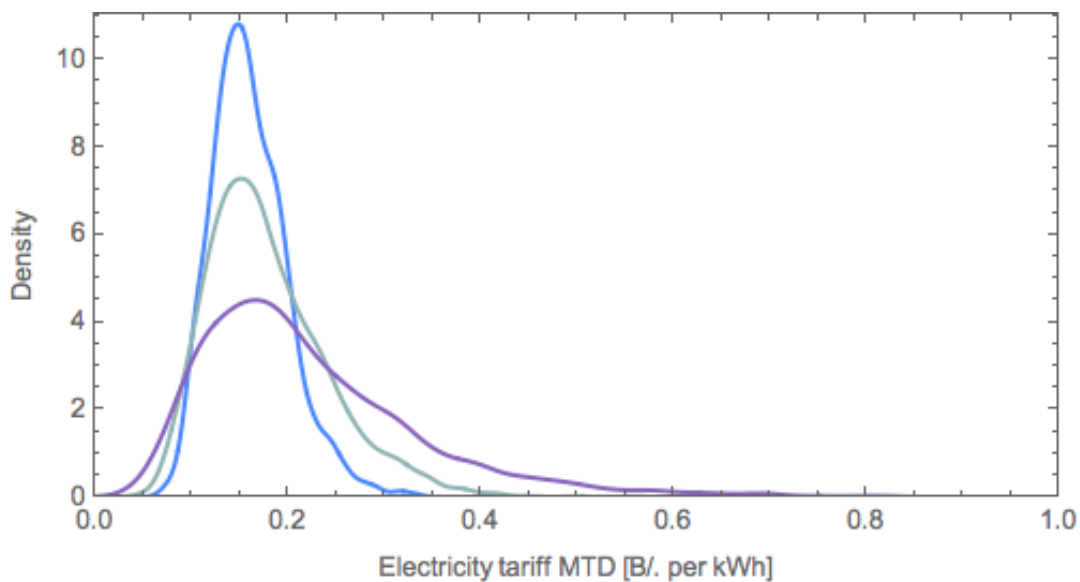


Figure 17. Distributions of electricity rates in the MTD tariff at 30, 60, and 120 months, based on GBM simulations

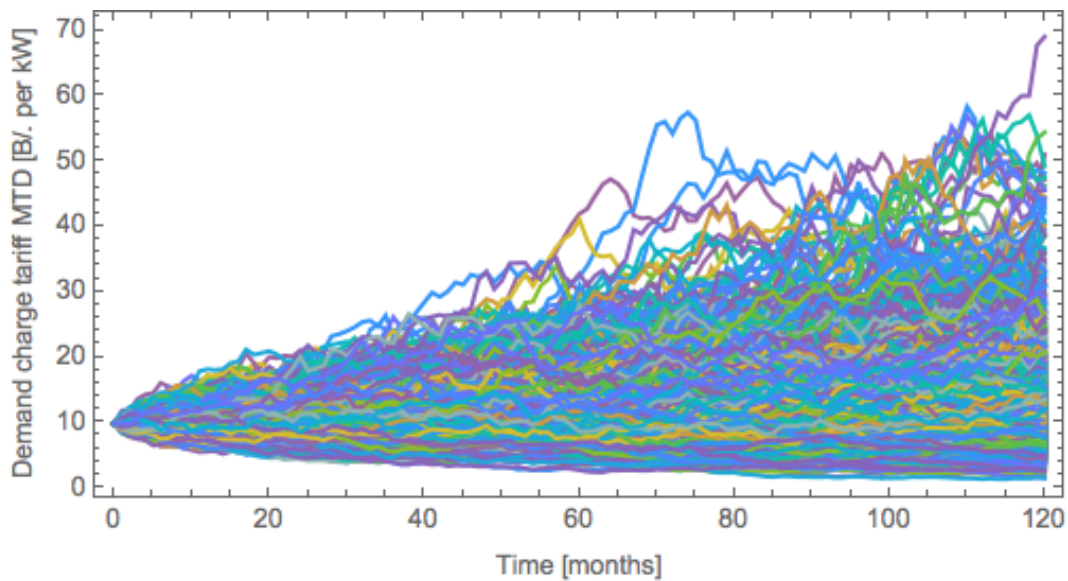


Figure 18. Simulations of the future evolution of demand charges in MTD tariff, following a GBM

Figure 19 shows the projected probability densities for demand charges at 30, 60, and 120 months. The observation is that demand charges have a higher variance than electricity rates.

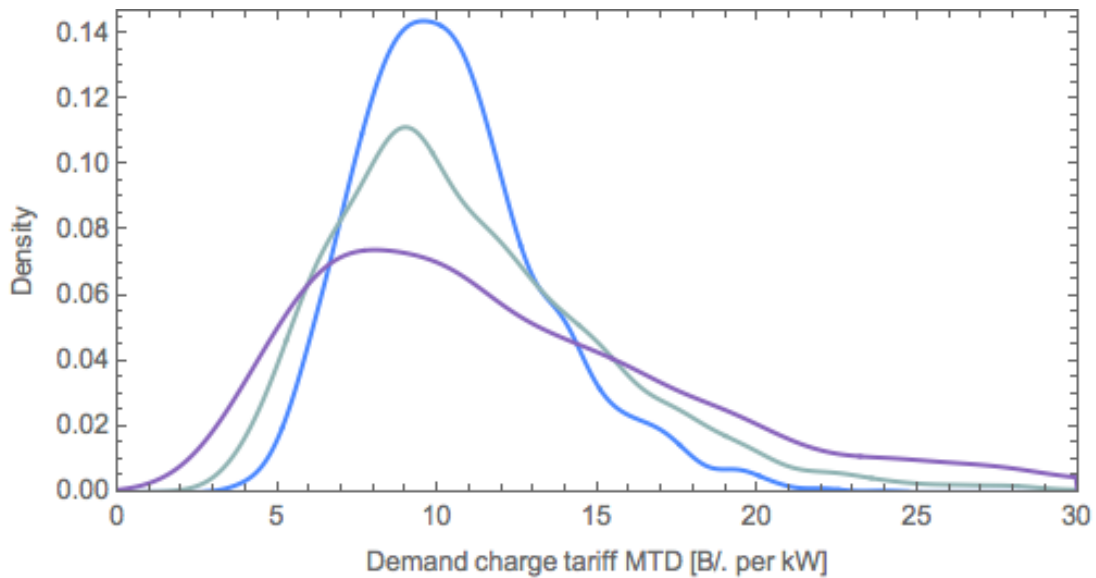


Figure 19. Distributions of demand charges for MTD tariff, at 30, 60, and 120 months, based on GBM simulations

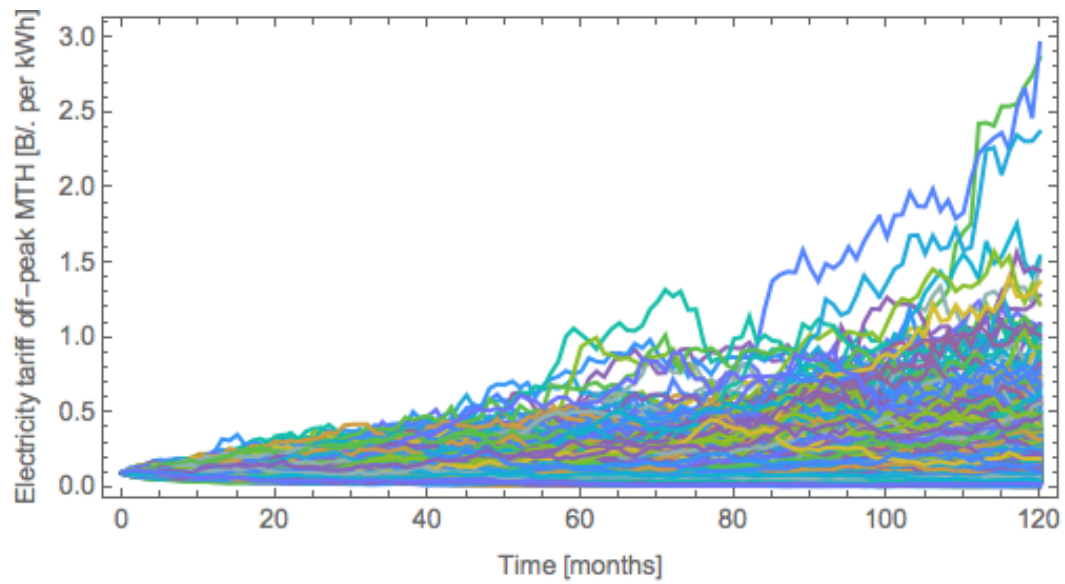


Figure 20. Simulations of the future evolution of electricity rates in off-peak MTH tariff, following a GBM

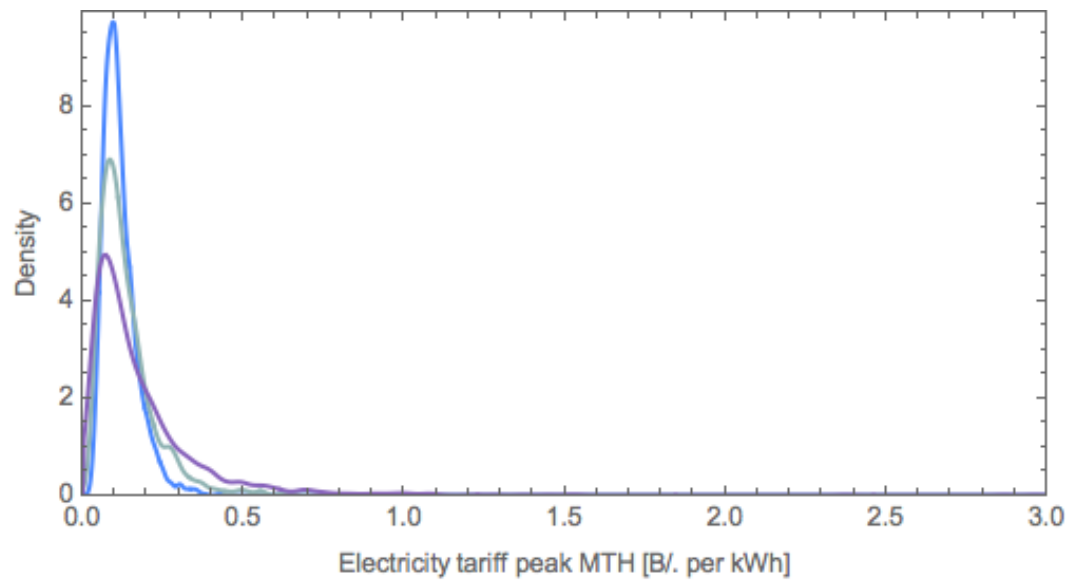


Figure 21. Distributions of electricity rates in the off-peak MTH tariff at 30, 60, and 120 months, based on GBM simulations

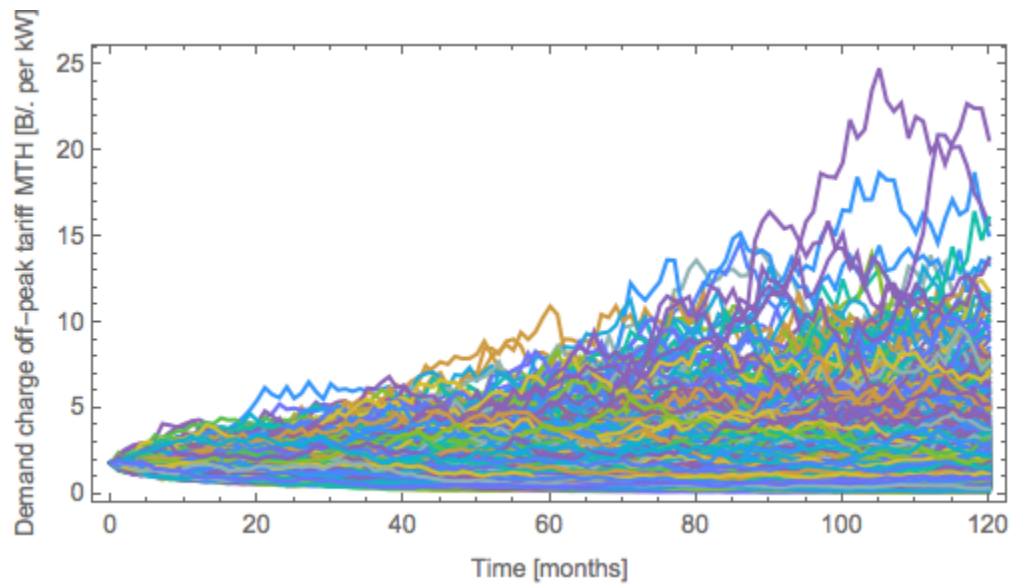


Figure 22. Simulations of the future evolution of demand charges in off-peak MTH tariff, following a GBM

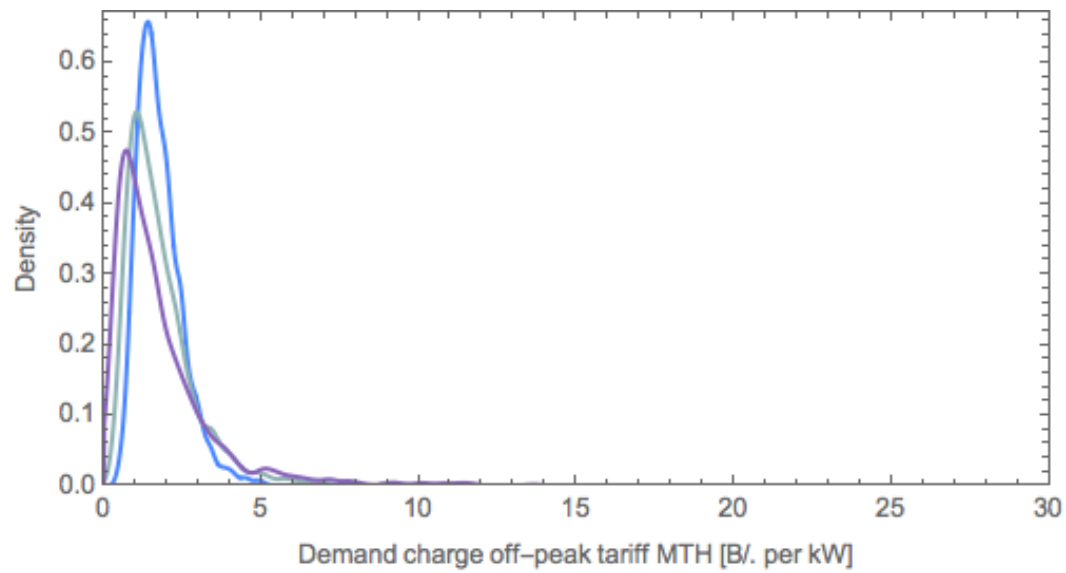


Figure 23. Distributions of demand charges for off-peak MTH tariff, at 30, 60, and 120 months, based on GBM simulations

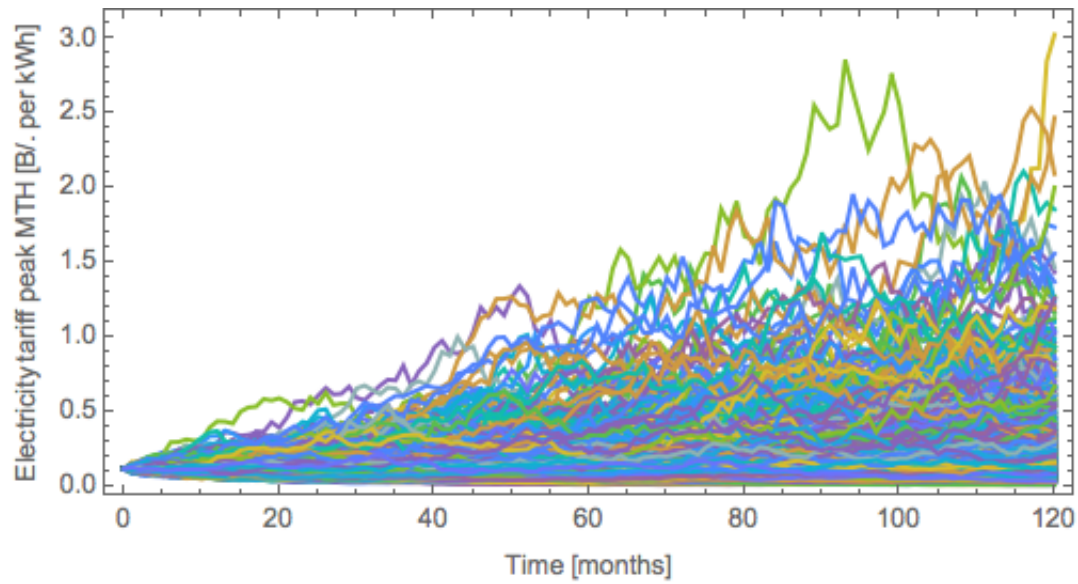


Figure 24. Simulations of the future evolution of electricity rates in the on-peak MTH tariff, following a GBM

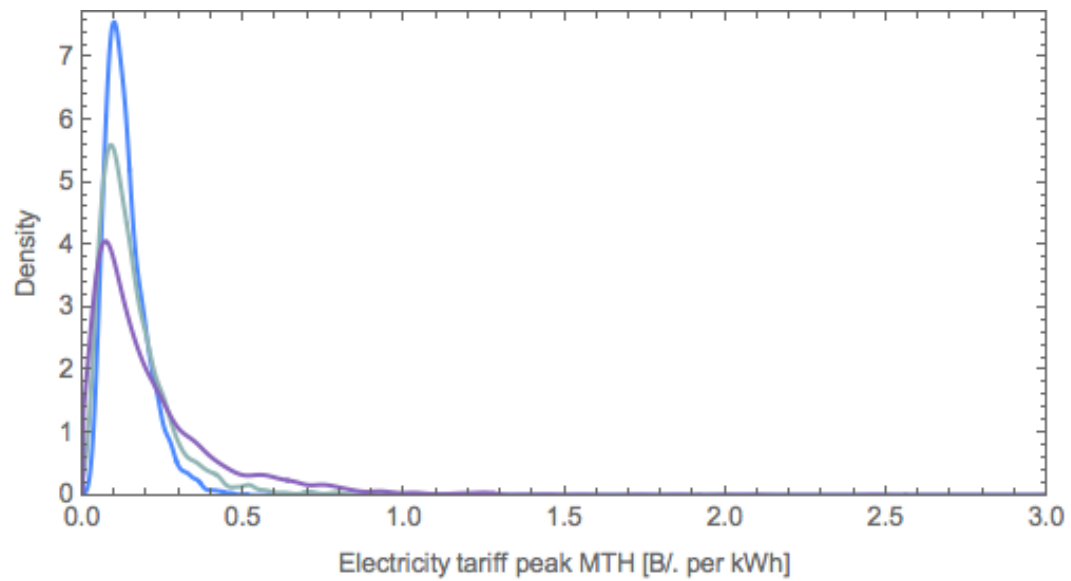


Figure 25. Distributions of electricity rates in the on-peak MTH tariff at 30, 60, and 120 months, based on GBM simulations

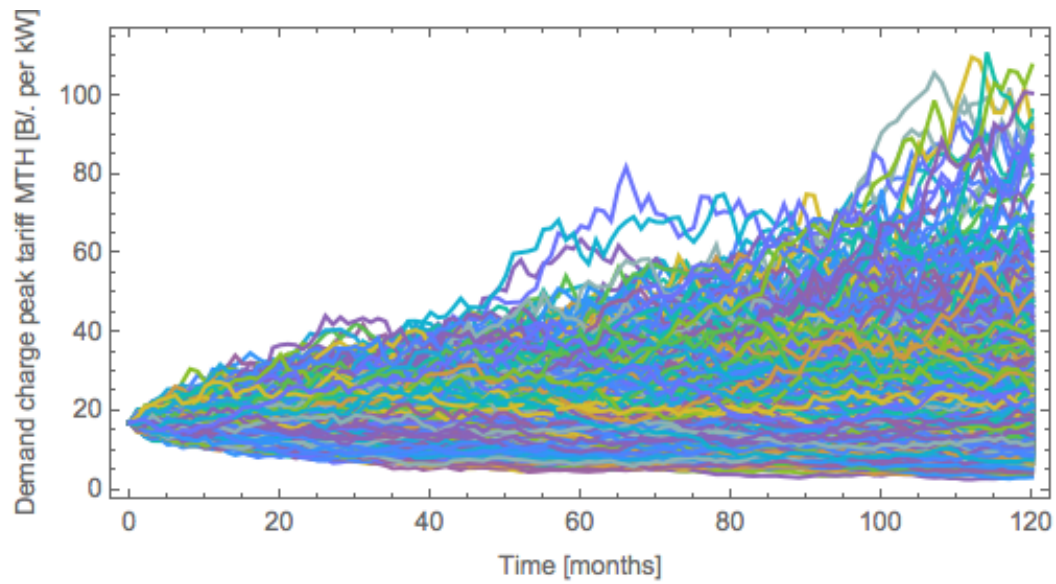


Figure 26. Simulations of the future evolution of demand charges in on-peak MTH tariff, following a GBM

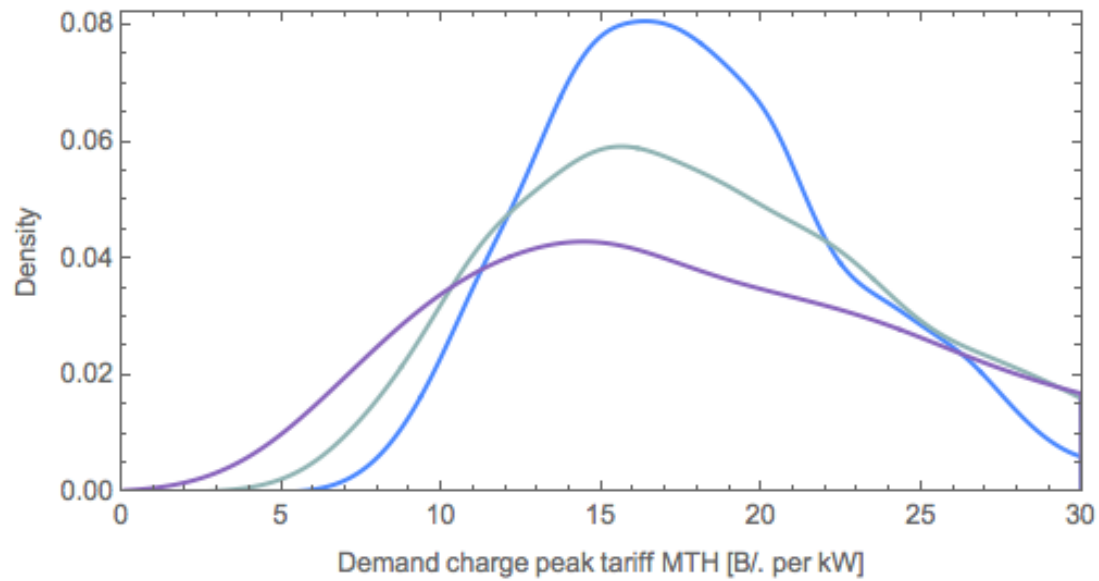


Figure 27. Distributions of demand charges for on-peak MTH tariff, at 30, 60, and 120 months, based on GBM simulations

7. Cost Analysis

The technology evaluation, included in a separate report, focused on ten service routes in Panama City, that were selected for the evaluation of technical performance under real-world local conditions of operation. For each of these routes, both rapid (or overhead) charge and slow (or overnight) charge technology configurations, as well as diesel and CNG platforms were evaluated. Table 3, Table 4, Figure 28 and Figure 29 summarize some of the characteristics of these routes and results derived from the technical evaluation. It is immediately clear from the figures that efficiencies can vary significantly *for the same bus*, depending on the operational context (drive cycles, route elevation profiles, passenger loads, etc.). This is the primary reason why conducting detailed technology assessments prior to procurement is so critical, to analyze technical viability and economic efficiencies. These results are integrated in the economic analysis that follows.

Table 3. Average operational characteristics of overnight-charging buses on each of the evaluated service routes

Route	Mean speed [km/h]	Passengers	Daily distance [km]	Distance between terminals [km]
DOMAL-G	17	37	406	33
DOMAL-R	20	42	481	36
TOSAL-G	34	17	628	36
TOSAL-R	31	17	601	37
VECMC-G	13	40	231	17
VECMC-R	15	42	266	17
SIRTC	12	33	236	14
CSFAL	22	27	397	18
CHOMA	9	9	168	8
MAMPK	12	25	234	17

Table 4. Operational characteristics of overhead-charging buses on each of the evaluated service routes during the most demanding peak-hour cycles

Route	Mean speed [km/h]	Peak-hour speed [km/h]	Passengers average peak-hour	Passengers average	Daily distance [km]	Distance between terminals [km]
DOMAL-G	17.3	12.9	79	37	406	33
DOMAL-R	20.2	15.4	79	42	481	36
TOSAL-G	34.1	22.8	59	17	628	36
TOSAL-R	31.3	19.8	54	17	601	37
VECMC-G	13.1	10.6	72	40	231	17
VECMC-R	15.1	13.9	80	42	266	17
SIRTC	12.4	9.5	79	17.3	236	14
CSFAL	21.9	19.1	61	20.2	397	18
CHOMA	9.1	8.0	33	34.1	168	8
MAMPK	12.2	12.3	79	31.3	234	17

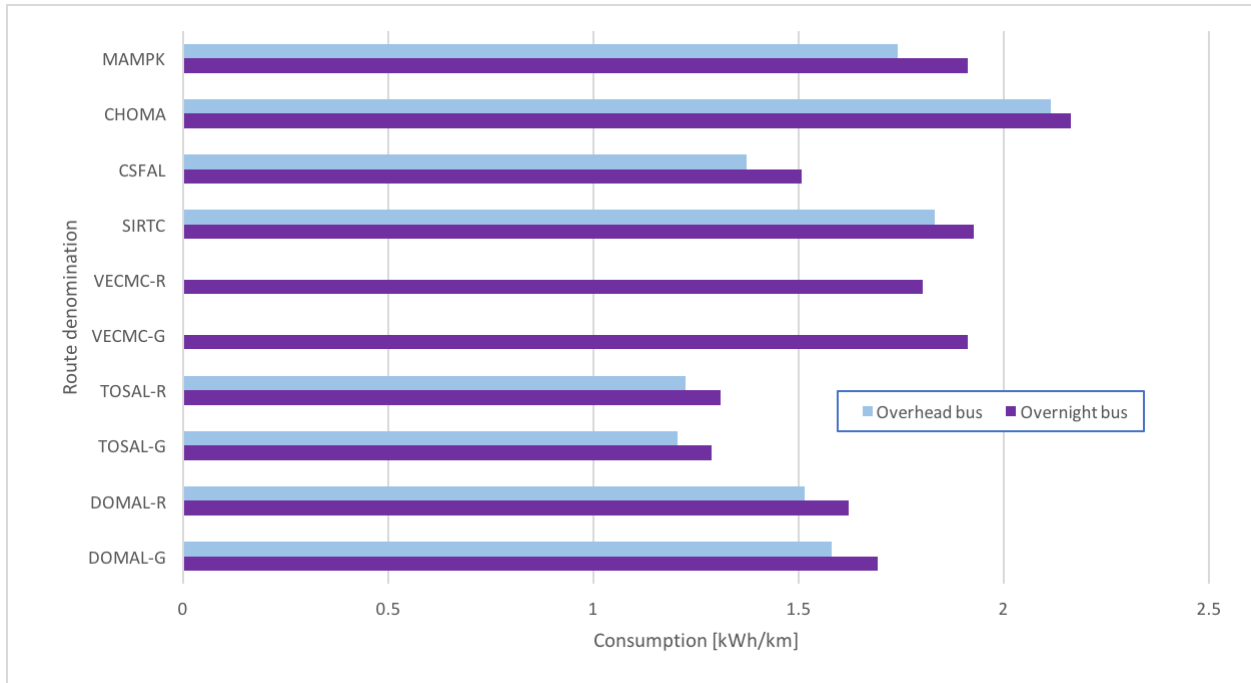


Figure 28. Energy consumption for battery electric bus configurations on each of the evaluated service routes

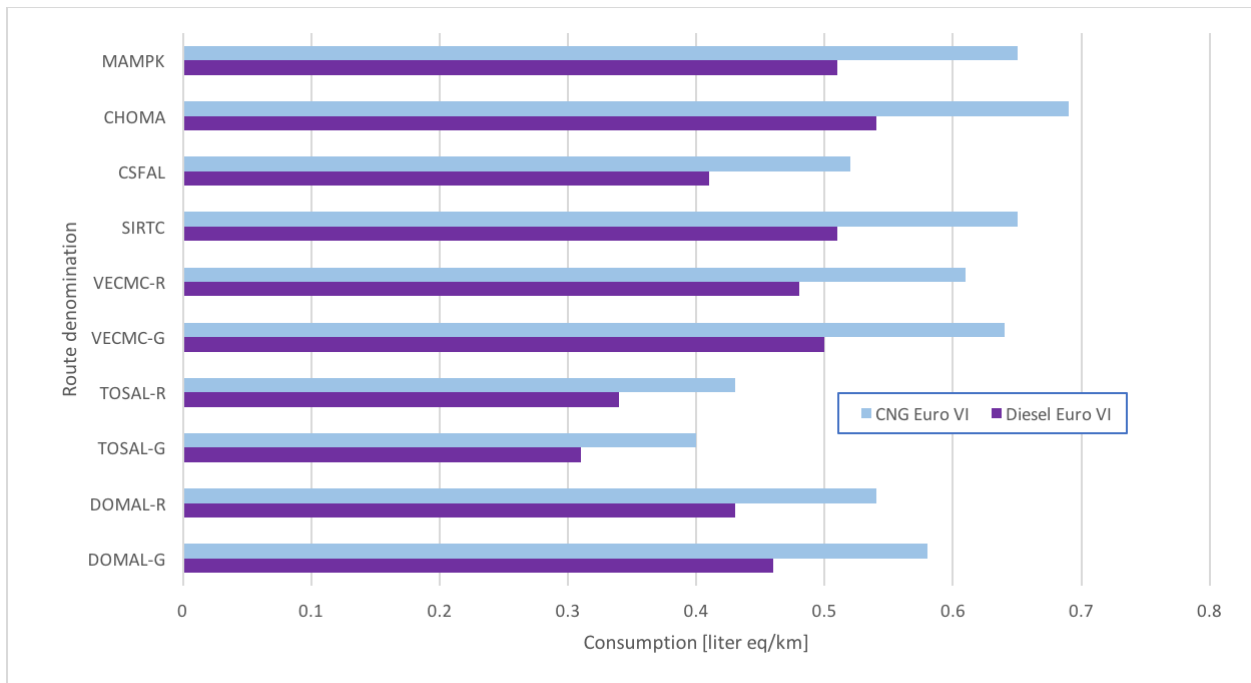


Figure 29. Energy consumption for fossil-fueled bus platforms on each of the evaluated service routes

The technology evaluation focused on overnight-charging and overhead-charging buses with onboard energy storage systems with nominal capacities of 324 kWh and 88 kWh, respectively. Given these technology parameters and other operational parameters

discussed in the technical evaluation report, bus ranges were obtained for each of the evaluated routes. With these ranges, it was determined that none of the routes that were examined could be served by overnight charging buses with the assumed configuration.⁵⁸ To illustrate the comparative economics of an overnight charging electric bus, a hypothetical shorter daily distance for the MAMPK route will be assumed.

Asset Service Life and Maintenance Practices

A key step to frame the financial analysis is to establish the expected lifetime of the project; for the case at hand, this relates directly to the expected lifetime of the bus. As indicated earlier, the simulations of energy prices assumed a time horizon of 10 years or 120 months. The service life of a heavy-duty transit bus has two faces: the normative and the actual. Normative service life is determined by manufacturer recommendations and by regulatory requirements, and is generally specified in terms of years and kilometers.⁵⁹ Manufacturers provide recommendations on maximum lifetime of their products, and these tend to vary between 12 and 15 years. Regulatory agencies may adopt minimum service life requirements in an attempt to create a framework for vehicle reliability and safety that deters *races to the bottom* in competitive procurement processes.⁶⁰ Actual vehicle service life refers to the number of years that units remain in service in real practice. This service life is framed by transit agencies' internal policies, which in turn are correlated with financial constraints. MiBus, specifically, reported an expected service life of 15 years or 1 million kilometers. An economic uncertainty affecting the batter electric technology is the rate of degradation that the battery pack will attain over its useful life. For the present analysis, it is assumed that the bus unit has a useful life of 10 years. This assumption is justified on the possibility to reassign units to routes with lower energy requirements for the last 1-2 years, if needed.

Vehicle service life, maintenance practices, and ultimately economics, are all affected by the rate of decay of the different components of the bus. The rate of decay is in turn impacted by annual kilometers, real conditions of operation, local climate, etc. Buses operating in Panama City face demanding urban conditions, with high ridership, tropical weather, prevalent aggressive driving behavior, and high average utilization as measured in kilometers. For example, on average, transit buses in the United States, the vast majority running on diesel or compressed natural gas, drive about 59,000 kilometers annually.⁶¹ This utilization falls well under the average for buses operating in Panama City.

It is important to note that for buses to attain their expected service life, they need to undergo significant rehabilitation of key components as part of their maintenance program.

⁵⁸ Further analysis would be needed to evaluate if any of these routes could be served with an overnight electric bus with a bigger onboard energy storage system.

⁵⁹ It is generally agreed that these metrics should also include an environmental component, to account for the conditions under which a given bus operates.

⁶⁰ The U.S. Federal Transit Administration adopted a 12-year minimum lifetime requirement for heavy duty large buses.

⁶¹ Based on NTD data.

Extensive overhauls are often performed around the 6th-7th year of operation, to replace/overhaul the drivetrain (engine and transmission), upholstery, windows, floors, etc., rebuild the brake system, perform technology upgrades, and other work.⁶² For the purpose of this analysis, an engine overhaul is assumed to take place at the 7th year of operation of the bus, both for diesel and CNG platforms. Independently of extensive overhaul practices, expensive maintenance events happen regularly during the life of the bus. For example, the drivetrain is replaced, approximately, every 400,000 kilometers, and the brake system is typically rebuilt every 25,000-35,000 kilometers. Decisions about the duration of the service life and about the performance of capital intensive maintenance events are intimately related.

From an economic standpoint, transit agencies may plan the service life of their vehicles as a minimization of the annualized lifecycle cost. The amortization of capital expenses over a larger number of years pushes to extend the service life, while the increase in operation and maintenance expenses with vehicle life pulls to constrain service life. The interaction of these drivers can point to a specific number of years of operation that would minimize the lifecycle cost. This exercise has been conducted for representative heavy-duty buses operating in the U.S. driving 35,000 miles, and found that minimum lifecycle costs are attained at around 13-14 years of operation.⁶³ A similar exercise for buses operating in Panama City, with higher average mileage, would likely render the age for minimum lifecycle costs lower than 13 years.

While informative, the economic analysis just described is not necessarily the best approach from a financial standpoint. Indeed, this is an example where the real-options approach that is used in this report is valuable. Given the uncertainties involved, the retirement of a vehicle is better viewed as an *option*. Of particular interest to the present analysis, a real-options analysis can help evaluate the marginal value of an additional year in service not only in the context of O&M costs but also in the context of replacement with alternative technologies.

Empirical evidence about the savings in maintenance costs that battery electric buses can deliver, relative to conventional platforms is varied. Maintenance costs are directly connected with the operational conditions facing the bus, and thus they are expected to vary across localities, service routes, random variation, etc. For example, an analysis of the maintenance costs of three BYD battery electric buses operating in the same university campus, reported costs of USD 0.16, USD 0.17, and USD 0.42 per mile for each of the units.⁶⁴ One area where battery electric buses offer savings is in the frequency of brake reline, due to the beneficial effect of regenerative braking. Some studies have found the associated repair costs in this category to fall by 55 percent.⁶⁵ Another area where battery electric

⁶² Extensive overhauls are not a rule and many agencies choose to perform maintenance on as-needed basis, thus spreading differently over time some of the costs.

⁶³ U.S. Department of Transportation, Federal Transit Administration (2007) *Useful Life of Transit Buses and Vans*. Report No FTA VA-26-7229-07.01

⁶⁴ Stanford University (2015) *Electric Buses at Stanford*. California Higher Education Sustainability Conference. June.

⁶⁵ California Air Resources Board (2016) *Literature Review on Transit Bus Maintenance Cost*. August.

buses offer maintenance savings relative to conventional buses is lubrication costs. This includes not only costs of scheduled maintenance, but also costs of supporting equipment and infrastructure. Transporte Masivo de Panamá (MiBus) installed a lubrication system in 2012 at a cost of B/. 92,713, including parts, labor, and tax.⁶⁶ Fleet operators are also sorely aware of problems related to downtime of refueling systems. Costs associated to the maintenance and repair of refueling equipment can also be significant. While no information was available about expenditures in this category in MiBus, the company reported the occurrence of downtime events and the complications derived from them for the operations of the fleet. This and similar costs are to be amortized among the fleet of buses served. Work order maintenance is calculated as

$$\text{cost/km} = (\text{labor} \times \text{rates} + \text{parts})/\text{kilometers}$$

Using empirical data from sound technical reports, and assuming labor hourly rates of B/. 20, an estimate for the average cost of maintenance of B/. 0.08/ km would be obtained for battery electric buses comparable to Proterra buses.⁶⁷ However, these types of buses are not currently available in the Latin America market. Based on multiple data points from various reports and anecdotal evidence from projects in different locations, a more conservative estimate of B/. 0.20/ km is used instead.⁶⁸

For diesel buses, using data from sound technical reports in the United States, assuming labor rates at B/. 20/hour, would suggest maintenance costs in the order of B/. 0.15/km.⁶⁹ Instead, data provided by MiBus suggests that the maintenance cost of diesel buses operating on trunclal routes is in the order of B/. 0.40/km, while for buses operating on corridors this estimates would decrease to about B/. 0.15/km. The large difference is attributed to the average age of buses operating on each type of route, to the longer average distances covered by buses operating on corridors, and the more damaging conditions of trunclal routes. The maintenance of CNG buses is in general more costly. Based on anecdotal evidence from various operators, these costs are assumed to be 1.3 times those of diesel buses.

As Table 5 shows, most of the routes that were included in the technical evaluation were trunclal.⁷⁰ To try to account for the age of the buses operating trunclal routes, a maintenance cost of B/. 0.35/km is assumed for diesel buses.

⁶⁶ Information provided by MiBus.

⁶⁷ National Renewable Energy Lab (2017) *Foothill Transit Battery Electric Bus Demonstration Results: Second Report*. Technical Report NREL/TP-5400-67698. June.

⁶⁸ In general, the data available to date on the maintenance costs of electric buses, particularly in Latin America, is not long enough to enable strong empirical inferences.

⁶⁹ National Renewable Energy Lab (2006) *King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results*. Technical Report NREL/TP-540-40585. December.

⁷⁰ The routes to be analyzed were jointly selected by LOGIOS and MiBus.

Table 5. Types of the routes included in the technical analysis

Route	Route type
CHOMA	Truncal
CSFAL	Truncal
DOMAL	Truncal
MAMPK	Truncal
SIRTC	Truncal
TOSAL	Corridor
VECMC	Truncal

Refueling Infrastructure

The analysis presumes that a procurement of a batch of buses will include an investment in refueling infrastructure for these buses. The amortization of the infrastructure costs will depend on the number of buses it serves. In general it is recommended that the planning of an investment in refueling infrastructure includes an expansion plan, to avoid duplicating expenditures in the likely case that more buses are added to the fleet.

Compressed natural gas (CNG) fueling systems are broadly classified in three types: time-fill stations (sometimes known as slow fill), cascade fast fill, and buffer fast fill. Each has pros and cons. Time-fill stations can involve lower capital expenditures, as they typically require smaller compressors, which feed into a manifold for multiple-bus refueling, and do not rely on storage capacity and cascading. This type of stations, however, make it more difficult to monitor the consumption of each of the bus units. In cascade fast fill stations, a larger compressor feeds a sequence of (typically three) high-pressure vessels, which in turn feed gas to the bus units at a higher flow rate. Typically, the construction of a bunker is for the storage tanks, and an acoustical enclosure around the compressor, are required as well. While the additional infrastructure makes this type of station more capital intensive than time-fill stations, the cascade fast fill station serves a bus at a speed comparable to diesel pumps, and makes it easy to measure the amount of gas going into each bus. Buffer fast fill stations are similar to fast fill stations, with the main difference that fuel is fed to the bus primarily from the compressor, and the storage is used only whenever the demand is higher than the capacity of the compressor. This last type of station is often used in fleet applications when buses are fueled sequentially. The capital expenditure in the implementation of a CNG refueling system can vary widely, depending on many factors, such as the inlet gas pressure, current and planned demand, refueling schedules, horsepower rating of the compressor, compressor redundancy, etc. For the purposes of the analysis, it is assumed that monitoring of the consumption of each bus unit is desired and that a fast fill station is the best solution. The installed cost for a fast fill station to support 150 buses is assumed at USD 555,000. This cost includes the items listed in Table 6.

Table 6. Itemized assumed cost of installation of a compressed natural gas station⁷¹

Item	Assumed cost (USD)
Gas supply line	20,000
Gas dryer	10,000
Compressor, 100 scfm, 2 units, 75kW	200,000
Storage vessels	70,000
Dual-hose metered dispenser x 2	90,000
Fuel management	15,000
Noise abatement	20,000
Canopy	20,000
Engineering drawings	10,000
Site work & installation	100,000
Backup generator	-
Station commissioning	-

The technical evaluation, presented in a separate report, included both overnight and overhead charging battery electric buses. The choice of vehicle type, as well as the associated charging strategy, will influence the overall economics of the asset system in a variety of ways. For example, it will determine how the cost of the charging infrastructure is amortized across vehicle units. Said in a different way, it will determine the investment in charging infrastructure needed to supply a given number of vehicle units.

Overhead charging equipment is more costly, but it has a higher utilization rate. For the present analysis, it is assumed that each such piece of equipment is able to supply 10 buses sequentially. The intention is to look for opportunities to maximize the utilization of these charging units, precisely to minimize the impact on the overall project economics. Thus, we observed that these units could be deployed in start/end points of the routes, locations which are shared with other lines. This way, even when some of the routes included in the analysis are served by fewer than 10 buses, vehicles from other lines could use the same piece of overhead charging equipment. Figure 30 is a diagrammatic map of the MiBus system, including markers for the locations of the starting or ending points for the routes included in the analysis, showing that these locations are shared with other lines.

⁷¹ Prepared from several references, including United States Department of Energy (2014) *Costs Associated with Compressed Natural Gas Vehicle Fueling Infrastructure*; LOGIOS (2019) *Gasificación del Transporte*; presentation for the Ministry of Transport of Argentina; Drive Natural Gas Initiative (n.a.) *CNG Infrastructure Guide*.

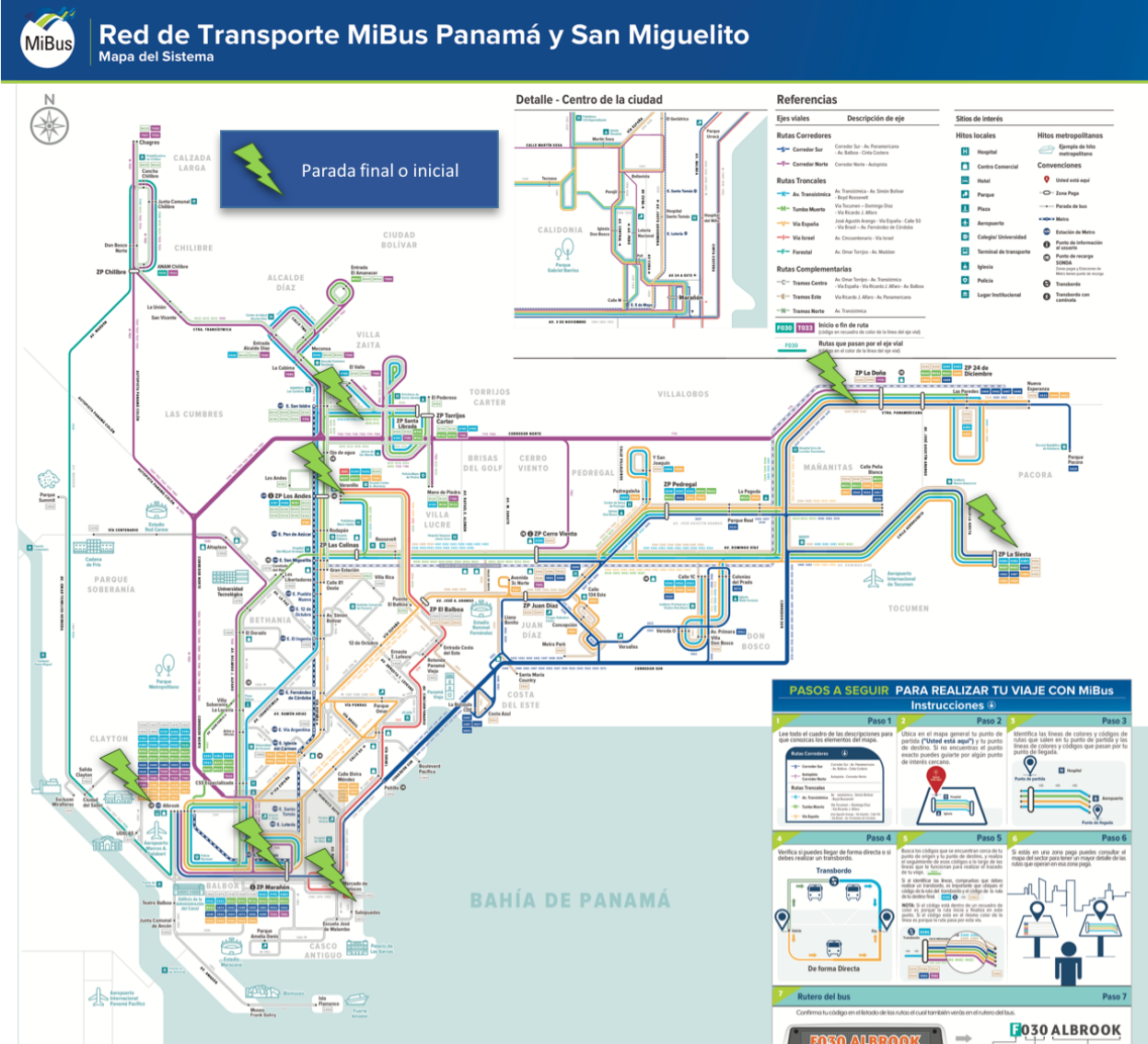


Figure 30. Identification of possible locations for shared overhead charging equipment in the MiBus system (Source: MiBus map, edited by LOGIOS).

For the present analysis, it is assumed that 80 kilowatt charging units are used for overnight charge and that each unit serves one bus. For overhead charging, equipment rated at 350 kilowatt that serves 10 buses is assumed.⁷²

Fuel Costs

The adoption of battery electric vehicles will naturally increase MiBus's electricity consumption. The bus depot at Ojo de Agua, to take one example, is served by a 500 kW main transformer, and reported maximum power demand of 198 kW on peak hour and an

⁷² In practice, the type of buses, characteristics of the charging equipment, and the number of charging units are determined via optimization algorithms. This type of analysis falls beyond the scope of the present work.

average monthly consumption of 91,620 kWh for the month of April, 2019.⁷³ Some of the depots are under MTD tariffs while others are under BTD tariffs. Depending on the extent to which any of the charging is done overnight, MiBus ought to consider moving to an MTH tariff.

Because the market for natural gas is still developing in Panama, there is less information available about cost structures. AES Panama built a terminal for the importation of liquefied natural gas (LNG) at Port of Colon, with onsite storage capacity of 180,000 cubic meters, a regasification facility, and truck terminal. The primary use of this natural gas is power generation, via combined heat and power plants. AES Panama imports LNG under a long-term take-or-pay agreement, with the French company Total as supplier. While the details of this agreement are confidential, it was learned that the agreed-upon prices have an adjustment clause pegged to Henry Hub's prices. Total can supply LNG from anywhere in its global portfolio of markets, although it is expected that the LNG arriving in Colon will predominantly originate in the United States.⁷⁴ LNG spot prices Henry Hub compare favorably with prices other locations such as Japan Korea Maker or Northwest Europe Maker. Given lack of further information on the supply agreement between AES and Total, the historical prices of LNG exports from the United States are used for the analysis (Figure 31).

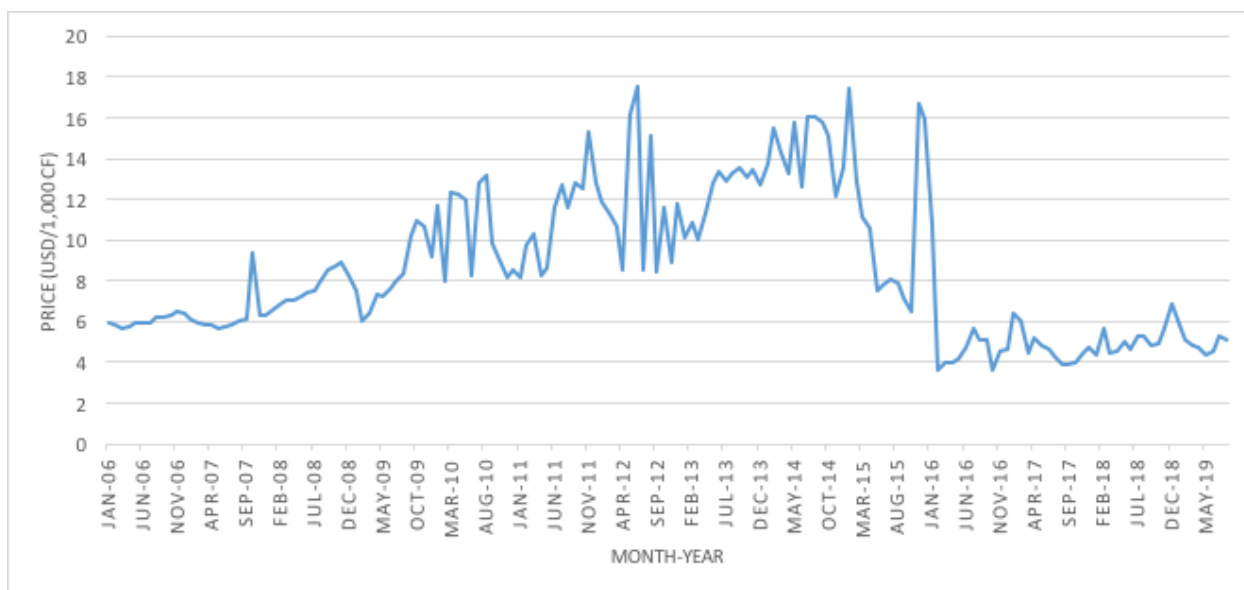


Figure 31. Historical prices of liquefied natural gas exports from the United States⁷⁵

The U.S. LNG export prices have remained comparatively low since 2016, due to a number of reasons, including a steep decrease in demand due to warmer weather, which increased inventories putting pressure on storage. That year, the U.S. became a net exporter of natural gas for the first time in 60 years, aided by strong investments in transport

⁷³ Data provided by MiBus.

⁷⁴ Information obtained in communication with AES.

⁷⁵ Data obtained from the United States Energy Information Administration.

infrastructure. The expansion of the Panama Canal in 2016 also helped the U.S. access natural gas markets in Asia. LNG is delivered to the Port of Colon in tankers, and the cost of this transport is assumed at USD 0.5 per MMBTU, for the purpose of analysis.

The LNG would be received at the Port of Colon, although it is unclear where in the distribution chain would the LNG be regasified. There is currently no established supply chain for the distribution of regasified natural gas for transportation applications. In a hypothetical scenario,⁷⁶ AES would transport LNG in trailers to demand centers, such as Panama City.⁷⁷ AES would establish agreements with local companies for the distribution of natural gas to consumption points. For the purpose of this analysis, it is assumed that MiBus would receive the natural gas in gaseous form. It is assumed that the reception at port and the regasification of the LNG add USD 0.5 per MMTBU to the cost of natural gas.

The CNG filling equipment includes a high-power compressor that is in operation many hours a day. To include the cost of the energy and power needed to operate the compressor, an MTD tariff is assumed. Because the price of natural gas is modeled as stochastic, the price of electrical energy for the particular case of the compressor is assumed as linear, in a fashion similar to the modeling of demand charges. Given that these costs are amortized among 150 bus units, their impact on the value of each bus is relatively small, but it is included in the analysis for completion.

Tangible Assets: Cost and Depreciation

The initial investment outlay includes cash expenditures in capitalized assets, specifically the buses and the fueling equipment.⁷⁸ The depreciation treatment of these assets is important to the overall financial plan because of possible value-of-time effects.⁷⁹ For this analysis, a *Sum-of-Years' Digits* method is used for the accelerated depreciation of vehicles and supporting equipment. This choice is justified by the type of assets (automotive), which have a steeper rate of depreciation earlier in their service life. The overall effect is to generate higher corporate tax savings (positive cashflows) toward the early stages of the service life of the vehicle. For a diesel bus of \$220,000 this results in a cashflow, before operating revenues, of \$911 in the first month, \$903 in the second month, etc. For an overhead charge electric bus of \$320,000 the cashflow derived from depreciation is \$1,388 in the first month, \$1,377 in the second month, etc. Because the depreciation rates are calculated assuming that the equipment degrades completely during its service life, the resale values are assumed to be zero at expiration of the service life. For cash that is expensed, such as cash to cover development costs, the tax considerations apply at that moment.

⁷⁶ Based in conversation with AES.

⁷⁷ LNG trailers have a representative capacity of 50,000 liters.

⁷⁸ Other possible forms of capitalized assets, such as new maintenance equipment, are not included here.

⁷⁹ The treatment that can be given to depreciation is typically affected by local law.

Table 7 shows the assumptions used for the market prices of capitalized assets, before VAT, and other factors included in the analysis. Notice that health costs, primarily from contributions to ambient air contamination, have not been included in the analysis.

Table 7. Factors included in the calculation of cash flows for each technology platform

Factor	Overnight charging electric bus	Overhead charging electric bus	Diesel bus Euro VI	CNG bus Euro VI
Bus cash expenditures	\$400,000	\$320,000	\$220,000	\$205,000
Charging equipment cash expenditures	\$40,000	\$160,000		
Fueling station cash expenditures			\$80,000	\$445,000
Importation fees	0	0	0	0
VAT			7%	
Corporate tax			25%	
Development costs	\$10,000	\$80,000	\$80,000	\$110,000
Electricity fuel	Stochastic (MTH off-peak tariff)	Stochastic (MTD tariff)		
Demand charges	Lineal (MTH off-peak tariff)	Lineal (MTD tariff)		
Long-term electricity tariff	Lineal	Lineal		
Fossil fuel prices			Stochastic	Stochastic
Bus work order maintenance	\$0.20/km	\$0.20/km	\$0.35/km	\$0.45/km
Fueling equipment repair	\$10/month	\$100/month	\$500/month	\$500/month
Depreciation	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years	Sum-of-years' digits, 10 years
Grid services	-	-		
Carbon price			\$10/ton CO ₂	
Health costs			-	-
Resale value	0	0	0	0

Cash Flows and Binomial Lattices

During the summary description of the real options method, the concept of the binomial lattice was brought up. A binomial lattice is a discretization of the discounted expected future cash flows that accounts for uncertainty in any of the underlying processes. As described earlier, the uncertainty incorporated in the present analysis is those in the evolution of prices of electricity, diesel, and natural gas. Cash flows are calculated for each of the nodes in the binomial lattice and then discounted to the present (or whenever the project is scheduled to start). The value of the investment is thus estimated and its viability

is assessed. The GBM simulations provided estimates of some of the parameters that are fed to a computational algorithm to construct the binomial lattices.⁸⁰

It is important to emphasize that the quality of the cash flow estimates depends heavily on the inputs used in the analysis. The estimates herein developed are based on the in-depth technical evaluation described in an earlier report. That evaluation, via the collection of data on the real-world operational conditions and the use of validated computational models, provided reliable estimates of the efficiency and energy demands of the buses in the specific routes in Panama City. Missing this type of information, any subsequent economic and financial analysis would be unreliable, and would significantly increase the risk of the related investment plan.

This analysis focuses on the comparative economics of battery electric buses vis-a-vis diesel and CNG buses. Starting from the premise that Panama *is* or *will* be interested in procuring buses (as opposed to evaluating *whether* investing in buses is a worthy), focusing on relative economics and financing allows the analysis to concentrate on the key factors affecting cash flow differentials. Table 7 shows the elements that are included in the calculation of cash flows for each technology at each node in the lattice.

The capital expenditure pertaining the charging equipment merits a little bit of further discussion. Overnight charge battery electric buses typically charge during off-peak hours at a centralized location, using charging equipment with nominal power rating in the neighborhood of 100 kW. While battery electric buses that charge overnight benefit from significantly lower electricity rates and demand charges, they require low buses-to-charging equipment ratios, typically 1 or 2. The implications for initial cash outlays is that the cost of each piece of charging equipment may be amortized only among two vehicle units at most. In contrast, overhead charging equipment is more capital intensive and has a higher nominal power rating,⁸¹ but they can accommodate much higher utilization rates and higher vehicle-to-charging equipment ratios.

Figure 32 shows the variation in the state of charge (SOC) of the onboard battery of the overhead charge electric bus considered, along the distance of one of the routes, on a peak-hour cycle.⁸² It can be inferred that the maximum energy needs of the bus at the end of a cycle can be tended in a few minutes with high-power overhead charging equipment. With frequent charging events lasting only a few minutes, each piece of charging equipment can be utilized by multiple buses, and thus the higher capital cost of this type of equipment can be amortized differently. The assumption made for the present analysis is that the same charging equipment is shared by 10 battery electric buses. The downside of this charging strategy may occur on the operations costs, because overhead charging typically occurs

⁸⁰ Binomial lattices can be computed manually for a few times steps, but their complexity increases rapidly with the number of steps. For the present analysis, considering in excess of 100 steps, the use of a computational algorithm is essential.

⁸¹ Typically, upwards of 300 kilowatts.

⁸² Thus, it represents a consumption profile under high energy requirement conditions.

during peak hours, which may expose the operator to higher electricity rates and demand charges. This risk can be addressed with long-term tariff agreements.

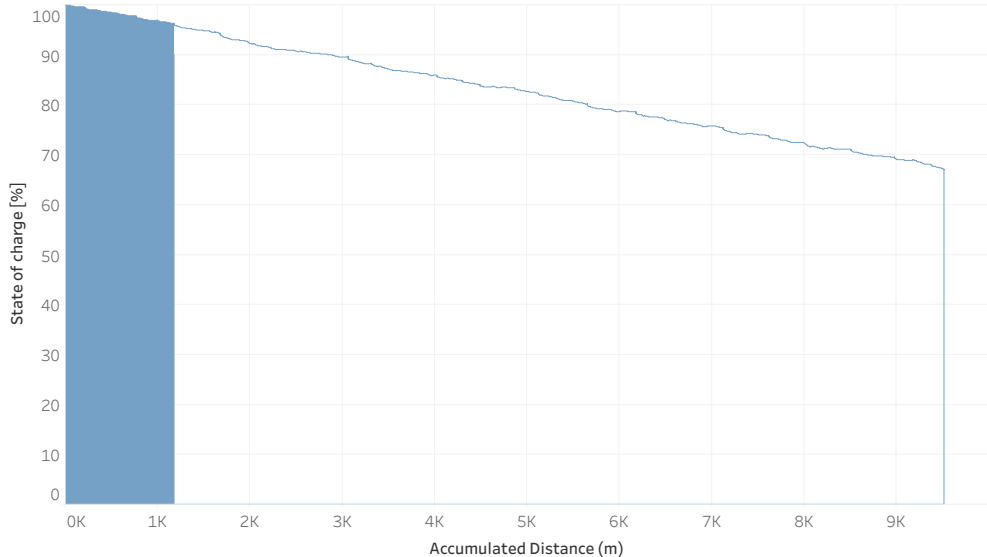


Figure 32. Variation in state of charge of the battery of overhead charge electric bus over the distance of the CHOMA service route, during a high-demand peak-hour cycle.

The category of development costs is project specific, and could include legal fees, permits, staff training, and other costs. An important case of development cost is that of charging and refueling equipment installation costs, including site development. While these costs are in practice often added to the cost of the equipment, for an adequate treatment of depreciation they are here taken separately. There are additional costs that would fall in the category of development costs and that could affect the differential in cash flows across technologies. The following were identified:

- Real estate costs. These can impact overnight charge electric buses, to the extent that additional land is needed to accommodate the charging equipment at the plazas.
- Upgrading of diesel dispensers and site clean up. The aging of the diesel dispensing equipment was not accounted for, but eventually equipment needs to be upgraded and site cleanup may be needed.
- Access to power. This will predominantly affect fleets of overnight charge electric buses that charge at centralized locations. As the fleet scales up the integration of electric buses, the aggregation of power demand of many charging stations at one site will require upgrades to the power supply system.⁸³ Based on information provided by the local electrical distribution company, power access would not be an obstacle to the installation of overhead charging equipment in urban areas.

⁸³ Based on consultation with electricity distribution companies in Panama, it is not yet established how these costs will be integrated into tariffs.

Next, results are presented for specific routes that were included in the technical evaluation. The technical analysis found that none of the routes that were evaluated could be served by an overnight charging bus with the configuration that was considered, because their total daily distances are longer than the expected range of the bus under the operating conditions specific to those routes. This finding limits the ability to perform an economic assessment of the overnight charging bus for any of these routes. Below, an approximation for the case of the overnight charging bus for one route will be proposed, to present approximate results. It should be understood, however, that an approximation is not meant as a substitute for the analysis of that route with a bus with the larger onboard energy storage system (such a bus would be constitutively different) or of a shorter route which could be served by the bus that was considered (different routes have different operating conditions).

8. Technology System Valuation for the Selected Routes

In this section, a comparative analysis is done for the competing technology systems, for each of the routes that were evaluated. The CHOMA service route is taken as a case study to explain the analytical process leading to the valuation of each of the technology systems. The analyses for the rest of the service routes will follow the same process, incorporating the information specific to each one. Summaries of the results of these analyses are included.

The CHOMA Service Route

Buses serving the CHOMA route travel 168 kilometers per day at an average speed of 9.1 km/hour, and a peak-hour average speed of 8 km/hour. The distance between terminals is just 8 kilometers. It was found that this route could be served by an overhead charging electric bus with no more than one charge event per cycle. Average efficiencies of the different technology platforms for this and all the routes considered, were shown in Figure 28 and Figure 29. An analysis for each of the technology systems is presented next.

Diesel technology

A diesel bus serving the CHOMA route is estimated to consume about 1,490 liters of diesel monthly. Figure 33 shows the first five time periods (months) of the value lattice for the diesel bus.⁸⁴ The lattice shows that the value of the investment in a diesel bus operating in the CHOMA service route at the beginning of the first month, net of capital expenditures and revenues, is estimated at -\$372,000. The two values in the second time period (the second month) represent the values of the project for the cases in which diesel prices went up or down, and accounting for other common changes in costs, like increments in cost of maintenance. The figures between parentheses are the estimated prices of diesel at the corresponding node. As a reminder, the cash flows that lead to this result include the elements in Table 7. The value in the first node in the lattice is then added to the capitalized cost of the bus and supporting infrastructure and the expensed development costs, to give the net present value per bus, before revenues (discussed below).

⁸⁴ Having taken one node for each of the 120 months of the analysis, it is impractical to show the entire lattice.

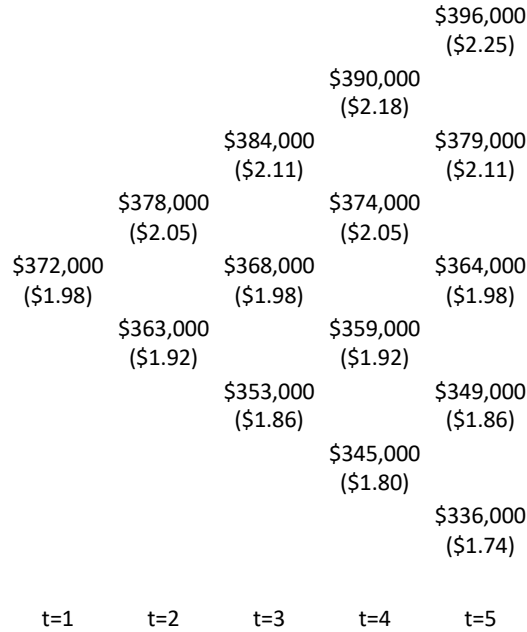


Figure 33. Value lattice of the diesel bus operating on the CHOMA service route, with diesel prices, in Balboas per liter, between parentheses (values rounded to the nearest 1,000).

CNG Technology

A CNG bus that served the CHOMA route is estimated to consume about 2,410 liters equivalent of natural gas monthly. The first five time periods (months) of the value lattice for the CNG bus are shown in Figure 34. As shown the value of the investment in a CNG bus to serve the CHOMA route would be approximately \$-225,000 at the beginning of the first month. This value is significantly better than that of the diesel technology, despite higher maintenance costs, primarily because of the lower prices of natural gas. Like before, the two values in the second time period (the second month) represent the values of the project for the cases in which CNG prices went up or down, and accounting for other changes in costs, such as increments in cost of maintenance. The prices of CNG at each corresponding node are shown between parentheses. When adding the value in the first node in the lattice to the capitalized expenditures and development costs, the net present value is obtained for each CNG bus unit. While the required cash outlay for the implementation of a CNG refueling station is significant, its impact of this cost on each bus is diluted by assuming that is amortized among 150 bus units.

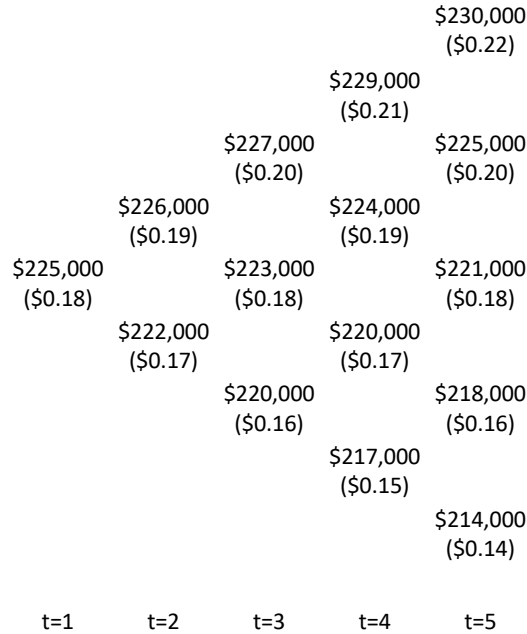


Figure 34. Value lattice of the CNG bus operating on the CHOMA service route, with CNG prices, in Balboas per liter equivalent, between parentheses (values rounded to the nearest 1,000).

Battery Electric Technology

An overhead charging battery electric buse, with the specified configuration, that served the CHOMA route is estimated to consume approximately 13 megawatt-hours of electricity per month. The results for the battery electric technology are presented for the two scenarios of energy prices discussed above, namely with regulated prices and with prices set by long-term agreements between supplier and end-user. For regulated prices, the MTD tariff is used, which would be more cost efficient than an MTH tariff, given that overhead charging electric buses consume power during peak hours.

Figure 35 shows the five time periods of the value lattice for the overhead electric bus operating in the CHOMA service route and subject to regulated tariffs for energy and power. The price of the kilowatt-hour in the MTD tariff at each node is shown between parentheses. It is found that the value at the beginning of the first time period is -\$184,000; a value significantly bigger (less negative) than that for the diesel Euro VI bus. When adding the value in the first node in the lattice to the capitalized expenditures and development costs, an estimate of the after-tax net present value for each overhead electric bus unit, before revenues, is obtained. This value is less negative than that for an Euro VI diesel bus, and more negative that that for a CNG Euro VI bus.⁸⁵ The economics of each overhead electric bus are improved by the assumption that the charging infrastructure is shared by 10 buses, although these are fewer than the 150 diesel and CNG buses assumed to share their respective refueling sites.

⁸⁵ It should be remembered that the analysis of CNG systems is based on less certain data than those used for diesel and battery electric systems.

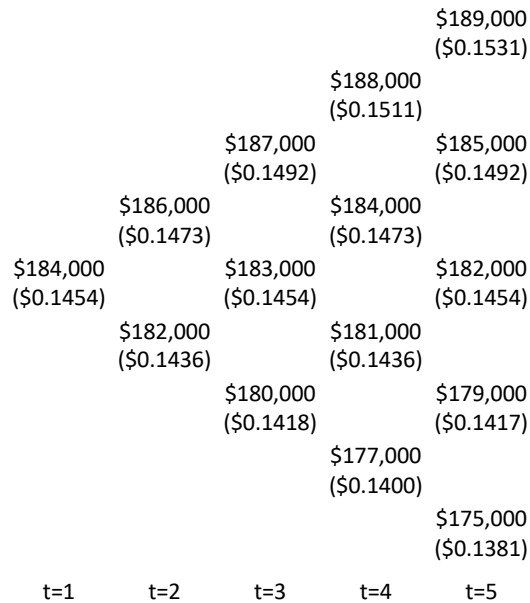


Figure 35. Value lattice of the overhead charge electric vehicle operating on the CHOMA service route, with the prices of the kilowatt-hour in the MTD tariff, in Balboas, between parentheses (values rounded to the nearest 1,000).

In this scenario, overhead battery electric buses are assumed exposed to MTD tariffs for both electricity and demand charges. The reason for this is that charging events for this type of bus occur during peak hours, while the bus is in service. These are the most demanding conditions for the economics of battery electric buses, particularly because of the differences in demand charges between the MTD and MTH tariffs, compounded with the significantly larger power draw for overhead, relative to overnight battery electric buses.

Figure 36 shows five time periods of the value lattice for the overhead electric bus operating in the CHOMA service route and enjoying lower, more stable energy prices, set with long-term agreement. Because of the absence of traditional volatility, the price of the price of energy shown between parentheses is the same for all nodes at a given point in time (month), and are adjusted monthly. These prices synthesize in one the prices of energy (kilowatt-hour) and power (kilowatt). The result is a significantly more attractive cost structure, that benefits the economics of the battery electric technology. As a direct consequence of the implementation of *market-based* prices, the value at the beginning of the first time period is found to be -\$119,000. In this scenario, where demand charges do not play a direct and significant role, the fact that a number of buses share the same overhead charging infrastructure has a lower impact on the economics of the overhead electric bus. When the capitalized expenditures and development costs are added, an approximate after-tax net present value, before revenues, is obtained for each overhead electric bus unit. The value is less negative and more negative than those for a diesel Euro VI bus and a CNG Euro VI bus operating on this route, respectively.

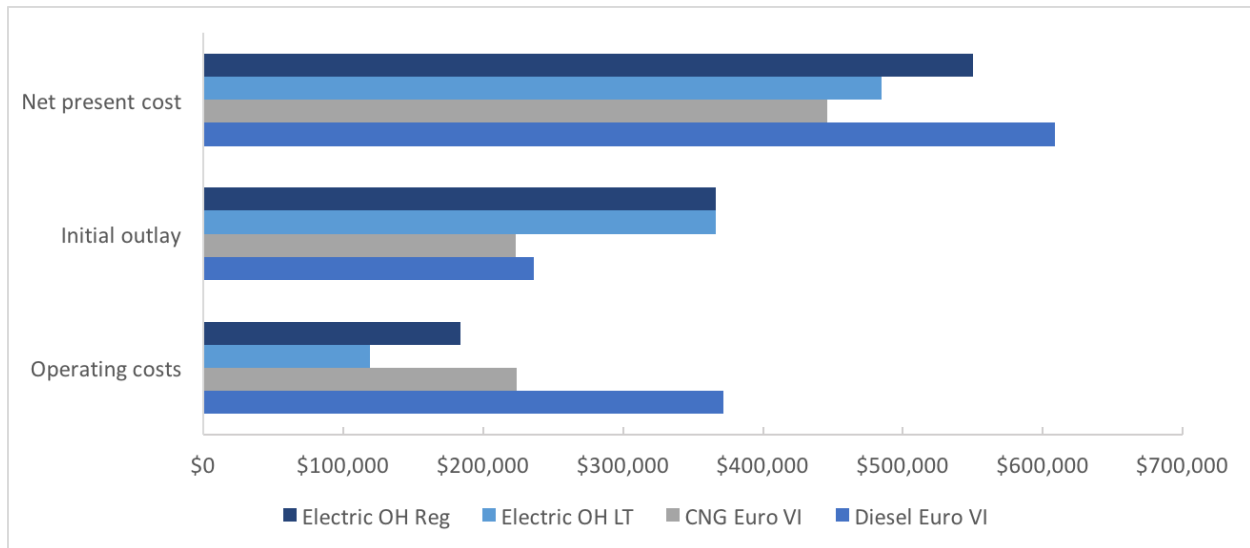


Figure 37. Summary of results of the valuation of the technology systems considered for the CHOMA route

The CNG Euro VI system has the highest estimated valuation, followed by the overhead battery electric system under a long-term tariff agreement, then overhead battery electric system under regulated tariffs, and finally the diesel Euro VI system.

The valuation of the technology systems is a central part of the analysis, but not the final step. Investment plan need to be developed, which could include different financing models, given the different characteristics of the technology systems. Preparing detailed investment plans is beyond the scope of the present analysis, but to provide some insight into this process, a discussion will be presented of cash flows and debt service payments.

To construct the value lattices, the lattice of cash flows was first calculated for each of the technologies on each route. The next step of interest is to use these lattices to compare the prospective cash flows of the technologies. The approach taken here is the following:

1. Characterize the distributions of cash flows in the nodes of the lattices for each time step and make assessments of the relative risks;
2. Calculate the median cash flow for each time step for each technology; and
3. Calculate the differential median cash flow.

The *differential* median cash flows at a given time step, represent the excess of operating costs of one technology relative to the other, net of operating costs that are common to all technologies. When the differences of cash flows across technology systems are taken, these common costs cancel out. Figure 38 shows box whisker plots of the cash flows for the diesel technology system every 12 months.⁸⁶ Figure 39 shows a similar chart for the case of the CNG technology system, while Figure 40 and Figure 41 show the charts for the battery electric technology system, using regulated and long-term energy tariffs, respectively.

⁸⁶ A box whisker plot conveniently shows the median, the 25% quantile, the 75% quantile, and the lower and upper fences of a dataset. It provides visual information about the median value as well as the spread of the values in the dataset.

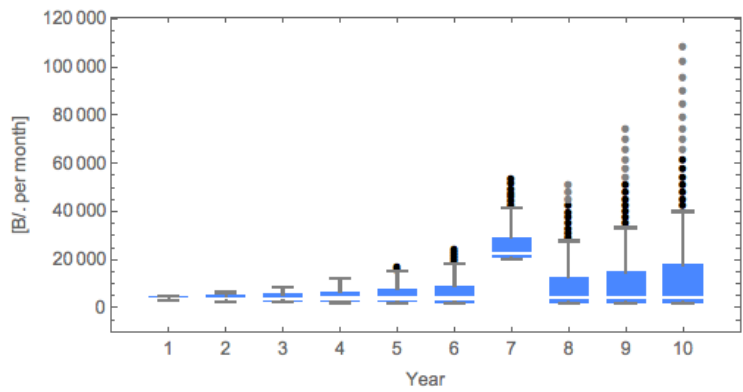


Figure 38. Box whisker plots of the lattice of cash flows for the diesel technology system on the CHOMA service route

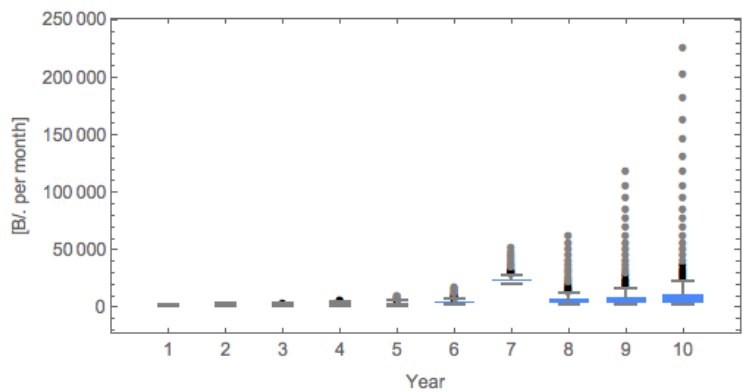


Figure 39. Box whisker plots of the lattice of cash flows for the CNG technology system on the CHOMA service route

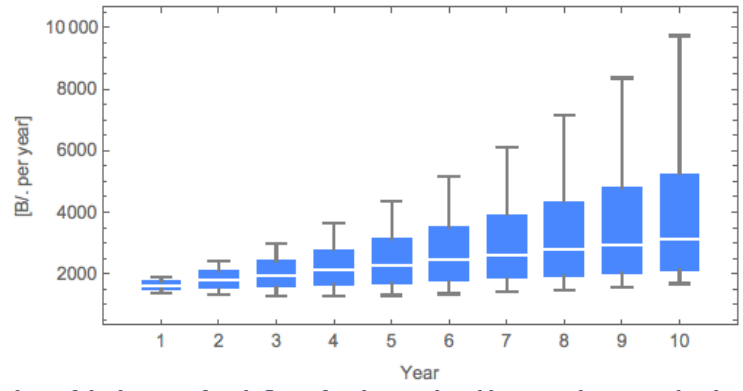


Figure 40. Box whisker plots of the lattice of cash flows for the overhead battery electric technology system, with regulated energy prices, on the CHOMA service route

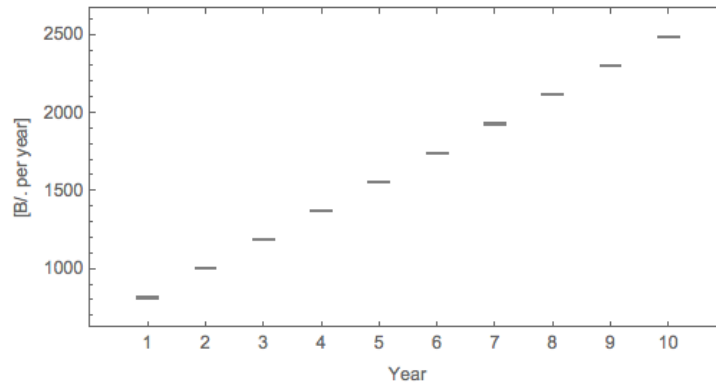


Figure 41. Box whisker plots of the lattice of cash flows for the overhead battery electric technology system, with long-term energy prices, on the CHOMA service route

Having calculated the median of the cash flows for the diesel bus and the overhead battery electric bus, the difference between the two can be calculated. These differentials are a representation of the expected excess in costs of the diesel bus over the overhead charging electric bus. These figures are after income tax and depreciation. They are not earnings in the traditional sense, though. Income tax applies only to depreciation, which for accounting purposes enters as income. Assuming that the bus operator has the income to cover the costs of operation of a diesel bus on the CHOMA service route, then the figures represent the savings on those costs that would be realized with the use of an overhead charging battery electric bus. Because these are values after income tax and depreciation, they are money available, for example for debt facility payments. Whether the expected realized savings can offset the debt service obligations will depend on the financing mechanisms, the procurement terms that can be negotiated, and other factors.

Using a simple scenario for the purpose of illustration, assuming that all technologies can access financing with loans at LIBOR + 9⁸⁷ and 10-year tenor, with a schedule of constant payments on principal and correspondingly decreasing interest payments, the results in Figure 42 are obtained. This chart shows the accumulation of operating costs and debt service payments for the first and last month,⁸⁸ for each of the technology systems. These results show the diesel Euro VI technology at a disadvantage compared to the other technologies and that the CNG Euro VI system is the most advantageous economically. Estimates for the overhead charging battery electric technologies, when the latter is subject to regulated energy tariffs, are significantly higher than those of CNG, but compete favorably with diesel Euro VI. Estimates for the overhead charging battery electric technology with access to long-term contracts for energy show the positive impact of this instrument in the economics of the technology system, and bring the electric technology system within competitive range of the CNG system. It should be noted that natural gas could also be supplied under long-term contracts, although the early stage of development of the natural gas supply chain in Panama, and the consequent limits on information, precluded an analysis of that scenario.

⁸⁷ LIBOR rate assumed at 3%, with high spread of 9%, to reach standard rates of 12%.

⁸⁸ Monthly payments are assumed, for simplicity.

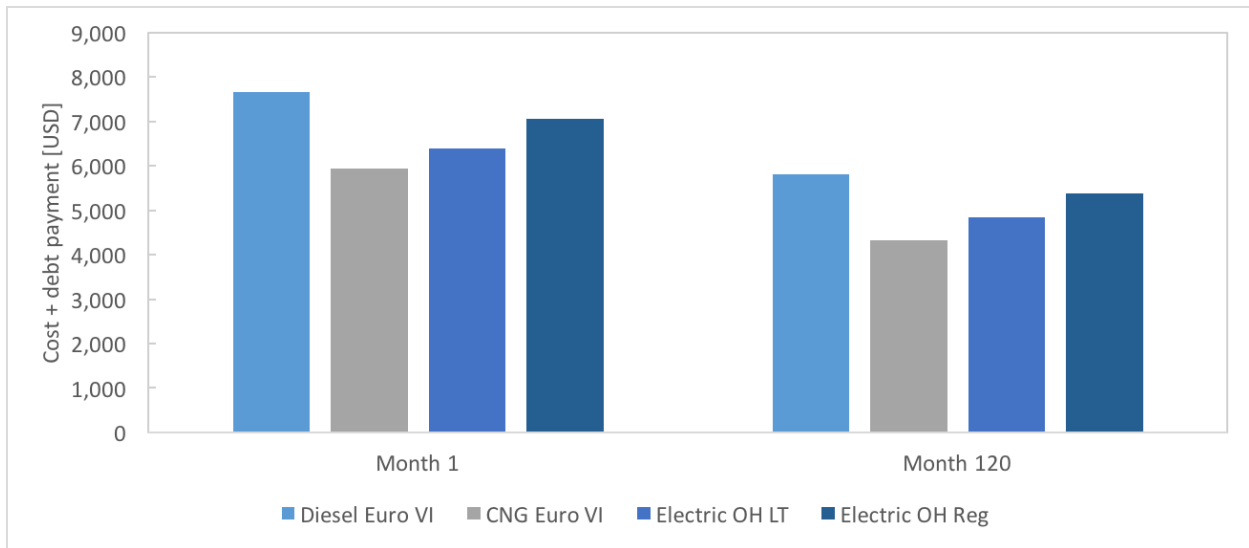


Figure 42. Operating costs inclusive of debt payments for first and last month, for each technology system on route CHOMA in the reference scenario

As discussed, investments in projects with social and environmental benefits may be able to access financing on preferred conditions, such as below market interest rates. To evaluate the potential impact of green financing on the economic competitiveness of battery electric technology systems, a scenario with interest rates at LIBOR + 3 is considered. The results, shown in Figure 43, suggest that the effect of lower interest rates competitiveness can be significant.

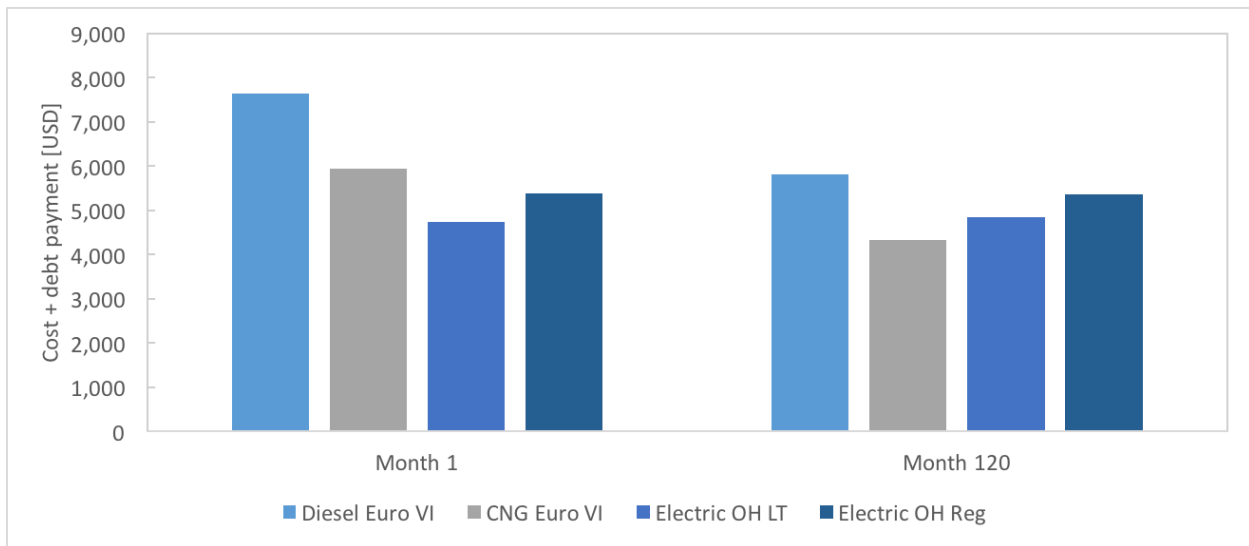


Figure 43. Operating costs inclusive of debt payments for first and last month, for each technology system on route CHOMA, using a LIBOR + 3 interest rate for the battery electric technology system

Another variable of interest pertaining the competitiveness of the battery electric technology is the capital expenditure. To examine the sensitivity of the results to

assumptions on the price of this technology, Figure 44 shows results when a 10-percent increment in the retail price of the overhead battery electric bus is used.

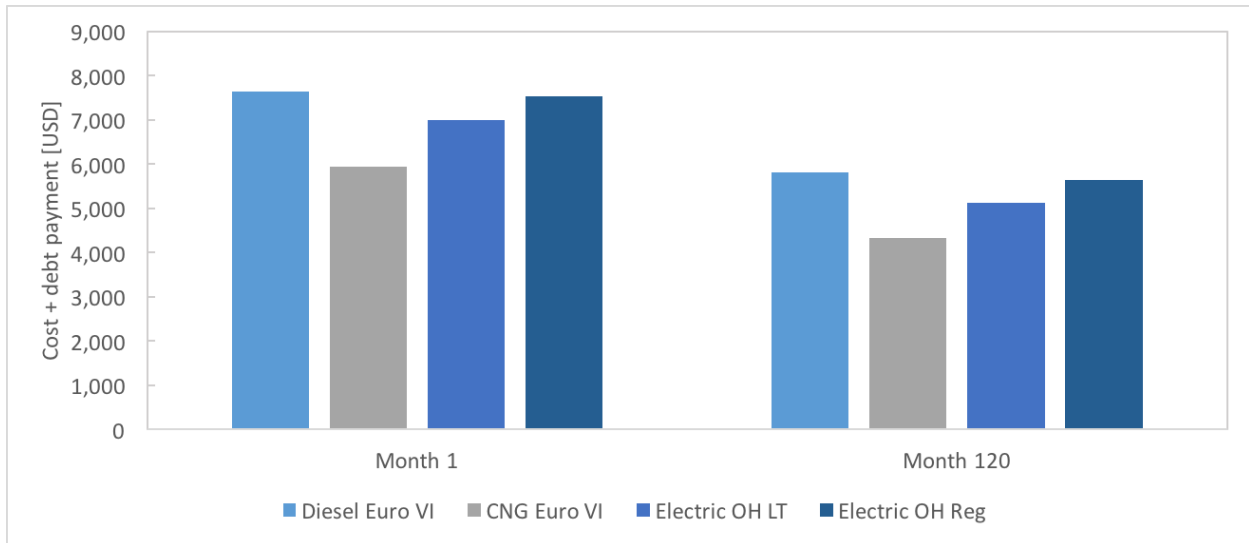


Figure 44. Operating costs inclusive of debt payments for first and last month, for each technology system on route CHOMA, with a 10% increase in the retail price of the overhead battery electric bus

Observation of Figure 38 and Figure 39 reveals that diesel and CNG buses expose operators to significantly larger uncertainties in cash flows. Larger cash flow differentials are available earlier in the service life of the vehicles, and this information should be integrated in the negotiation of the schedule of payments.

There are alternative models to finance the procurement of battery electric buses. One of such models centers on the utilization of the savings just described to fund a tariff that the bus operator could pay a creditworthy entity that takes the loan for the procurement of bus (or components of it) and charging equipment.

Brief Investigation of the Overnight Charge Electric Bus

The technical evaluation demonstrated that an overnight charging electric bus of the configuration that was considered, would not be fit to serve any of the selected routes. In order to provide some insights on the economics of overnight charging buses, models are run for the MAMPK route, assuming it served a 50-percent shorter daily distance, or 160 kilometers.

The results are shown in Figure 45 and Figure 46. Even when the overnight configuration is highly competitive on an operating cash flow basis, the capital cost of the technology assets makes the net present cost comparable to or higher than the diesel technology, depending on the terms of procurement of electrical energy. These results can be compared with those for the MAMPK route using the real daily distance, which are shown in Figure 47 and Figure 48, to examine the sensitivity of the results to the utilization of the technologies, as measured in lifetime kilometers. The results validate the intuitive hypothesis that the

comparative economics of electric buses improves with higher utilization. While for the real distance of the MAMPK route the overhead electric bus system with stable energy prices compares favorably with the CNG bus system, the opposite is true when the route's daily distance is reduced.

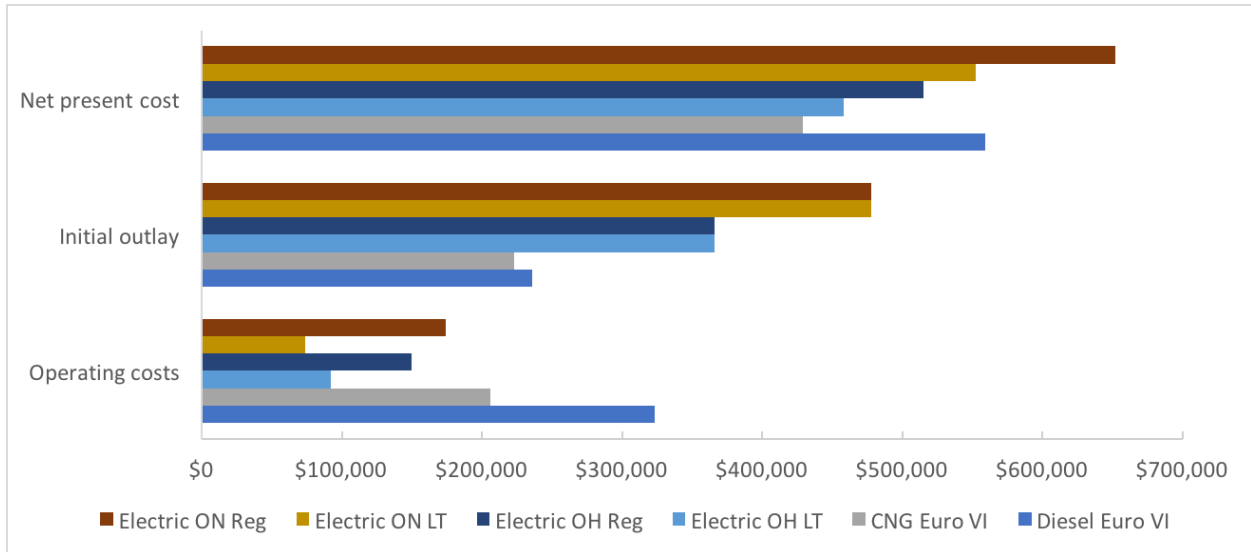


Figure 45. Summary of results of the valuation of the technology systems considered for the MAMPK route, assuming a shorter daily distance.

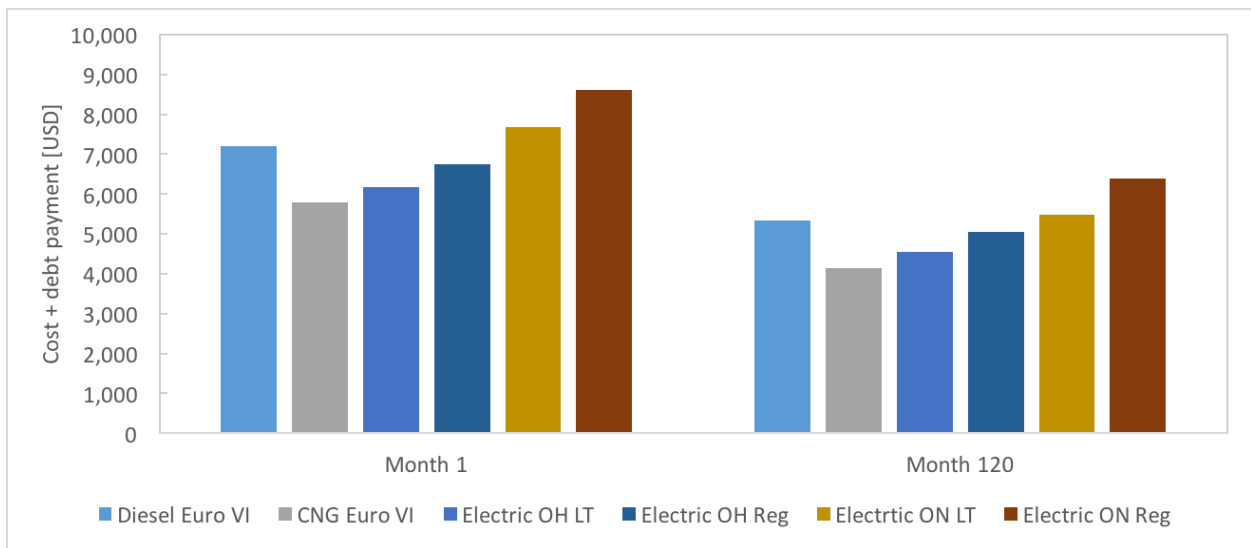


Figure 46. Operating costs inclusive of debt payments for first and last month, for each technology system on route MAMPK, assuming a shorter daily distance.

Other Service Routes

The valuation of the competing technologies for the rest of the routes can be done following the same process used for the CHOMA route. Below, a series of figures is included with summaries of the results.

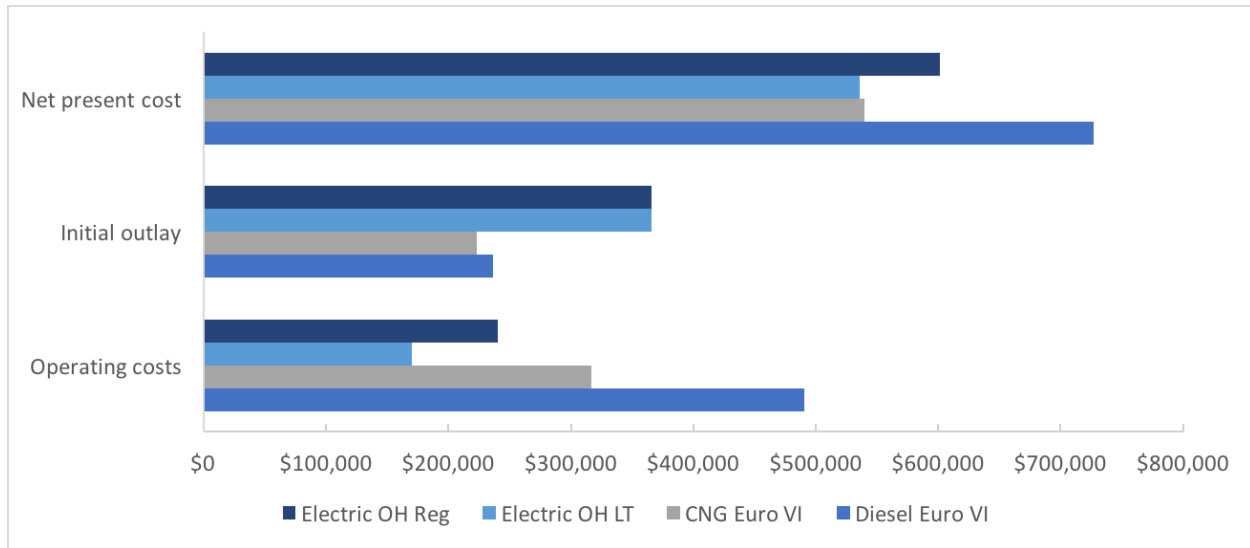


Figure 47. Summary of results of the valuation of the technology systems considered for the MAMPK route

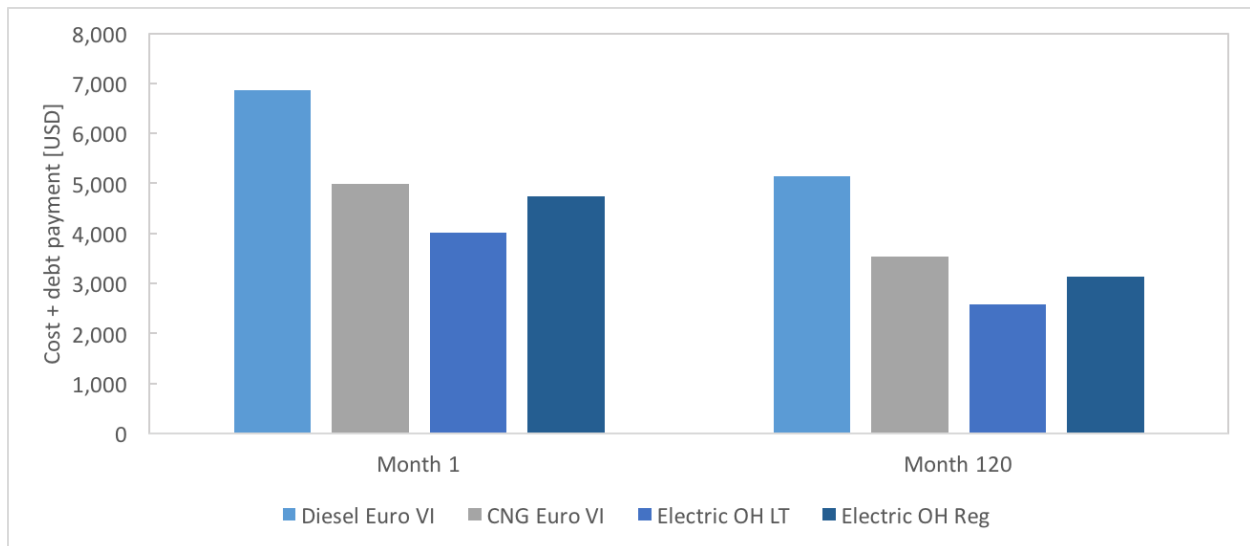


Figure 48. Operating costs inclusive of debt payments for first and last month, for each technology system on route MAMPK

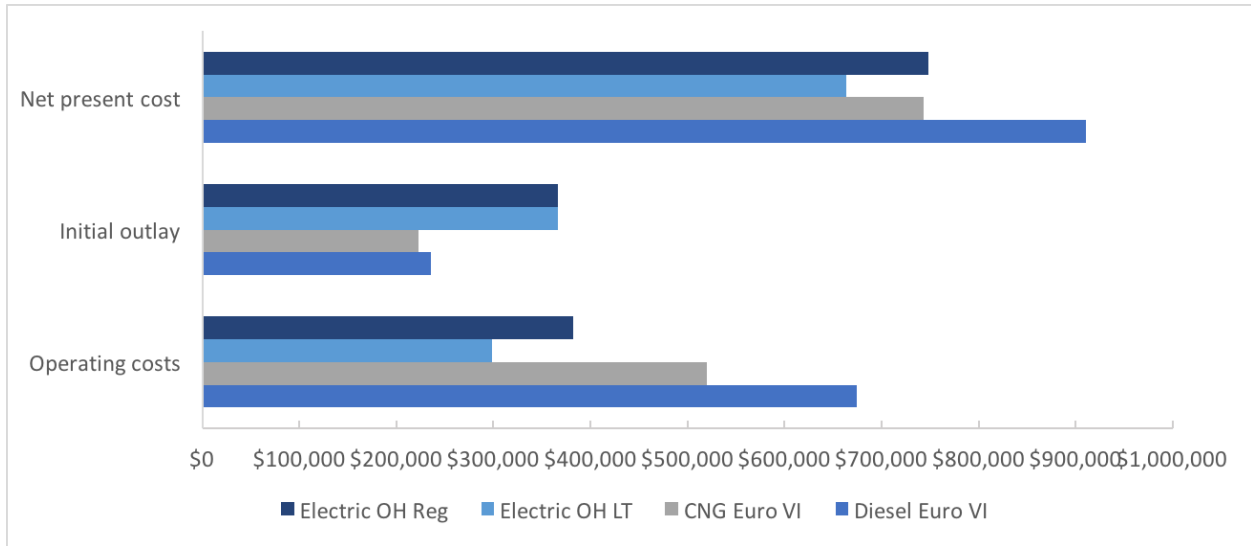


Figure 49. Summary of results of the valuation of the technology systems considered for the CSFAL route

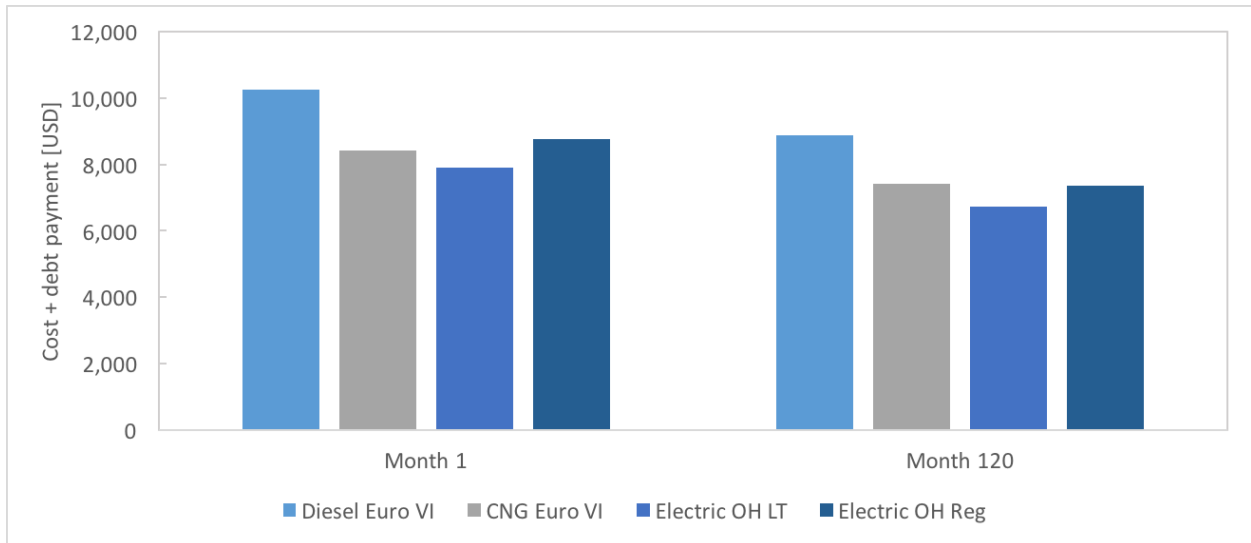


Figure 50. Operating costs inclusive of debt payments for first and last month, for each technology system on route CSFAL

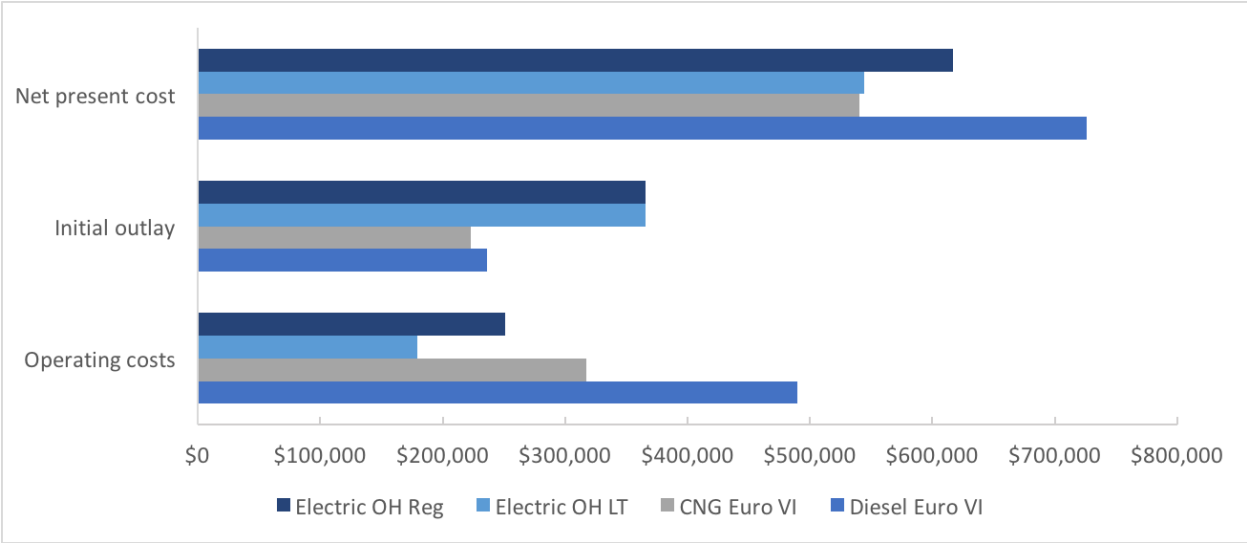


Figure 51. Summary of results of the valuation of the technology systems considered for the SIRTIC route

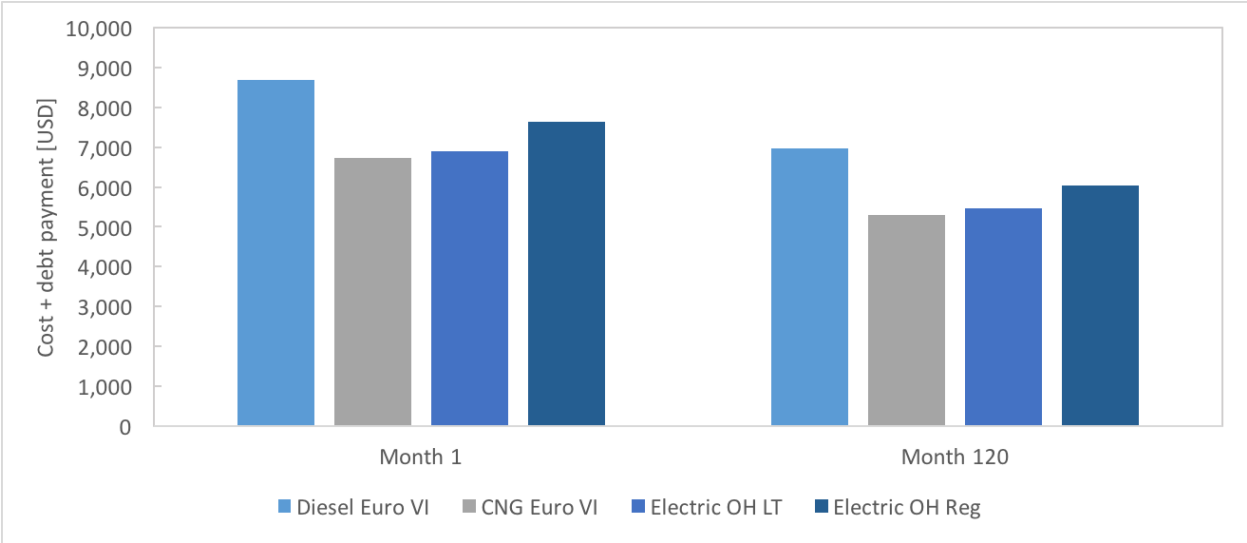


Figure 52. Operating costs inclusive of debt payments for first and last month, for each technology system on route SIRTIC

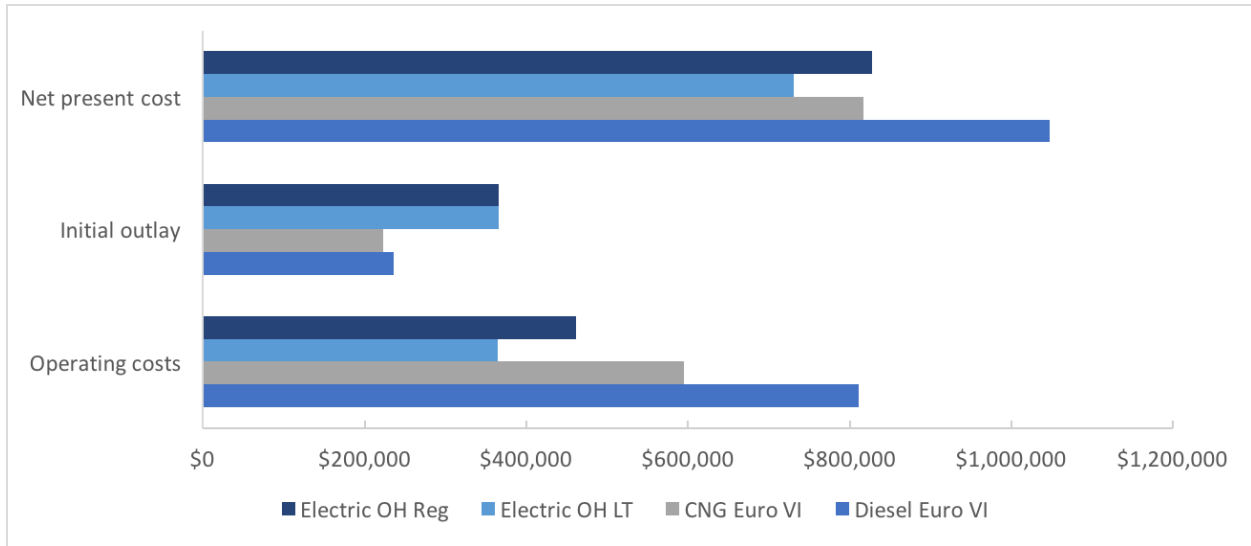


Figure 53. Summary of results of the valuation of the technology systems considered for the DOMAL route

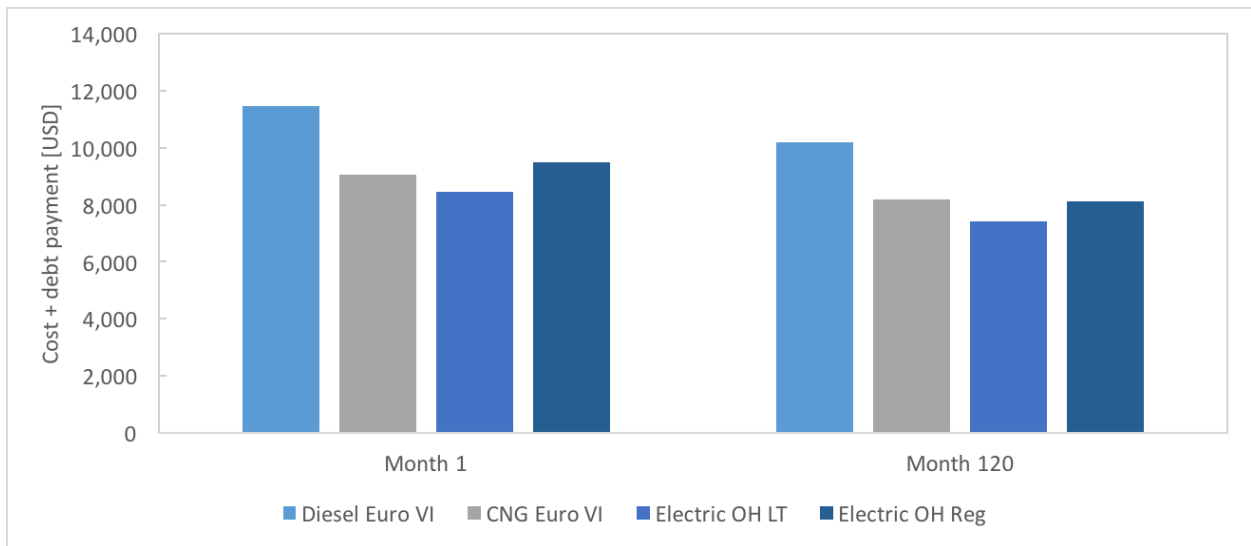


Figure 54. Operating costs inclusive of debt payments for first and last month, for each technology system on route DOMAL

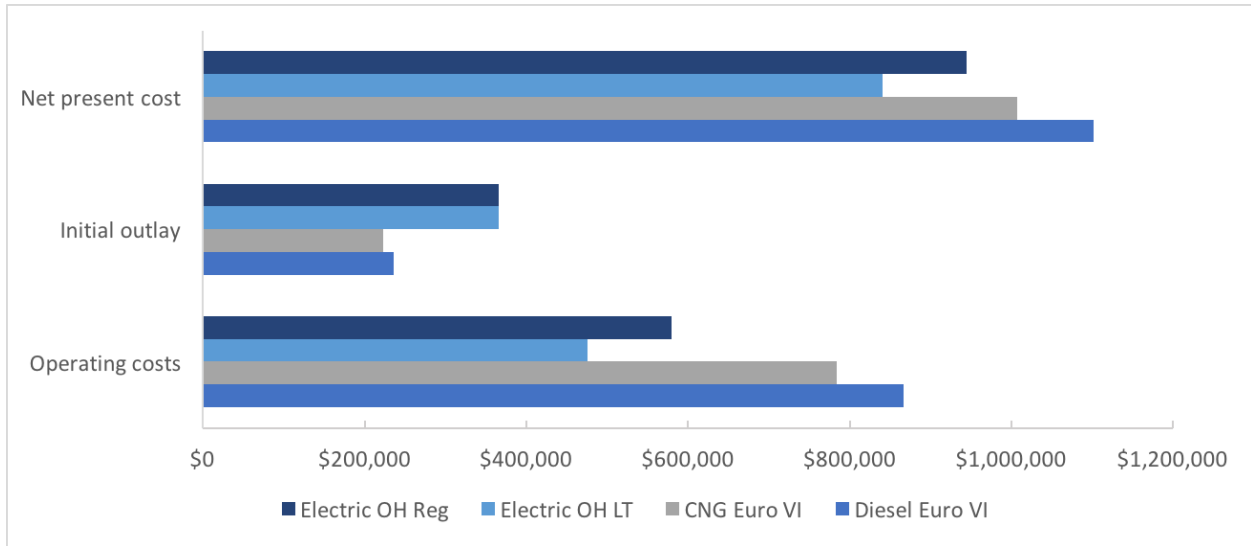


Figure 55. Summary of results of the valuation of the technology systems considered for the TOSAL route

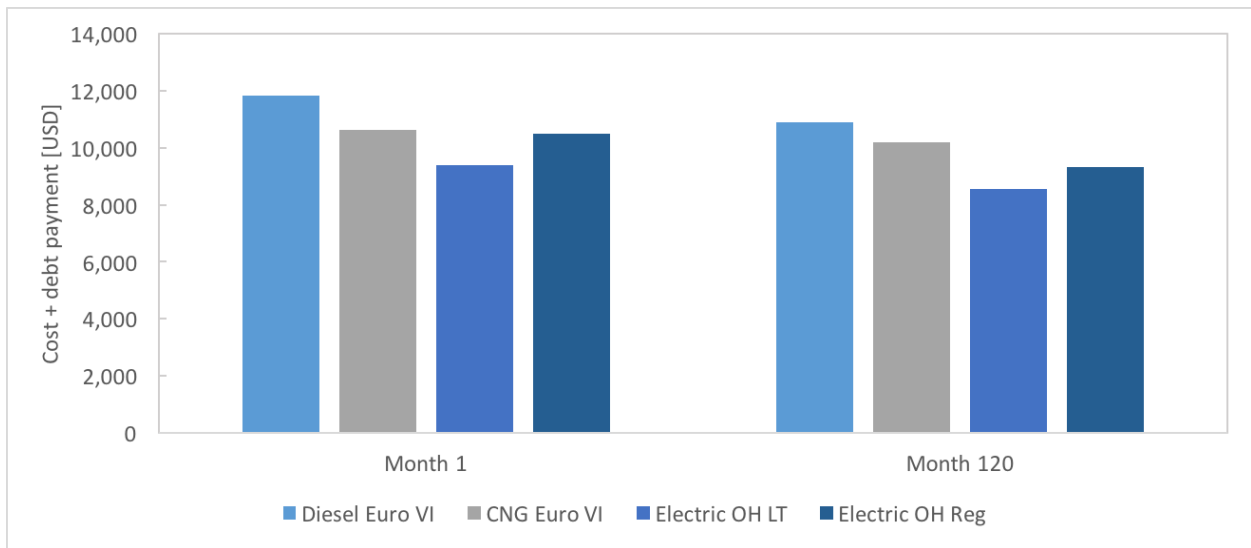


Figure 56. Operating costs inclusive of debt payments for first and last month, for each technology system on route TOSAL

9. Final Remarks

This report presented a comparative economic-financial analysis of battery electric buses, diesel buses, and CNG buses for Panama City, building upon the results of the technology evaluation that was conducted and presented in a separate report. To provide some context, the technology evaluation carried out a process of field data collection using precision GPS equipment, to develop realistic drive cycles and characterize the operational conditions in various public transport routes in Panama City. The drive cycles were fed into high-precision models and computationally analyzed. As a result of this analytical process, reliable estimates of vehicle performance were obtained for the specific operational conditions in each of the service routes in Panama. The technical evaluation thus provides a fundamental building block for the analyses presented in this report; without it, the economic and financial analyses would have had to rely on proxy technical information that would not be representative of local operational conditions.

The analysis presented in this reported covered a wide range of areas, from the treatment of risk in projections of fuel prices, to the integration of battery electric buses with the electric grid, to the valuation of the competing technology systems. The primary results are comparisons of these valuations for the routes that were considered, to evaluate the relative competitiveness of each technology system for a variety of operational condition.

Below, a list of key considerations arising from the analysis is proposed:

- The analysis demonstrates the **critical importance of conducting detailed technology evaluations** that account for local operational conditions. Economic and financial analyses that would not build upon such evaluations would yield unreliable results. Similarly, investments that are not informed by such evaluations are exposed to significant risks. Pilot projects are not an alternative to technology evaluations; instead they can play an important role in validating the results of evaluations.
- The integration of electric bus systems with the grid can uncover myriad latent value streams. Materializing these value streams will require a modern grid with a system of price signals, organized under institutionally robust markets. Among other, battery electric buses are well poised to provide frequency response services. To support transportation electrification, **Panama should consider developing a modern market for ancillary services.**
- Diesel Euro VI bus systems will have problems maintaining their competitiveness. The results presented here show that they tend to fall behind CNG buses and overhead electric buses on an economic basis. This will be compounded by increasing pressures to put the transportation sector in a trajectory of environmental sustainability.
- From an economic perspective, this analysis shows **no universal winner**. Both overhead battery electric buses and CNG buses are competitive, and which takes precedence depends on a variety of factors, including the operational characteristics of the route, the capital costs of the vehicles, the terms of financing, among others. The results do support the intuitive hypothesis that competitiveness of electric

buses increases with utilization; the more kilometers they travel, the more savings they provide.

- The results do provide sufficient grounds to believe that electric buses are a technically and economically viable option for some public transport routes in Panama City. Should the government adopt the strategic position of fostering electromobility, the technical analysis of more routes should be conducted, along with an analysis of operations and of the network of charging locations.
- **Long-term contracts** to firm up the price of electricity are a powerful instrument to enhance the economic competitiveness of electric buses. In fact, the analysis suggests that absent these instruments, it may be more difficult for the battery electric bus to compete with the CNG bus.
- The supply chain for compressed natural gas is not developed in Panama yet. As a consequence, the analysis of the CNG technology system had to rely a larger number of assumptions. It is not obvious, at this point and given the size of the potential market, whether developing the necessary supply chain will ultimately be attractive. The main stakeholder in the natural gas industry in Panama, AES, invested in the LNG Colón terminal, along with a 381 MW combined cycle power plant, to participate in the electricity market. This suggests that AES may also have a vested interest in the electrification of transportation.

Appendix 1
Supplementary Figures

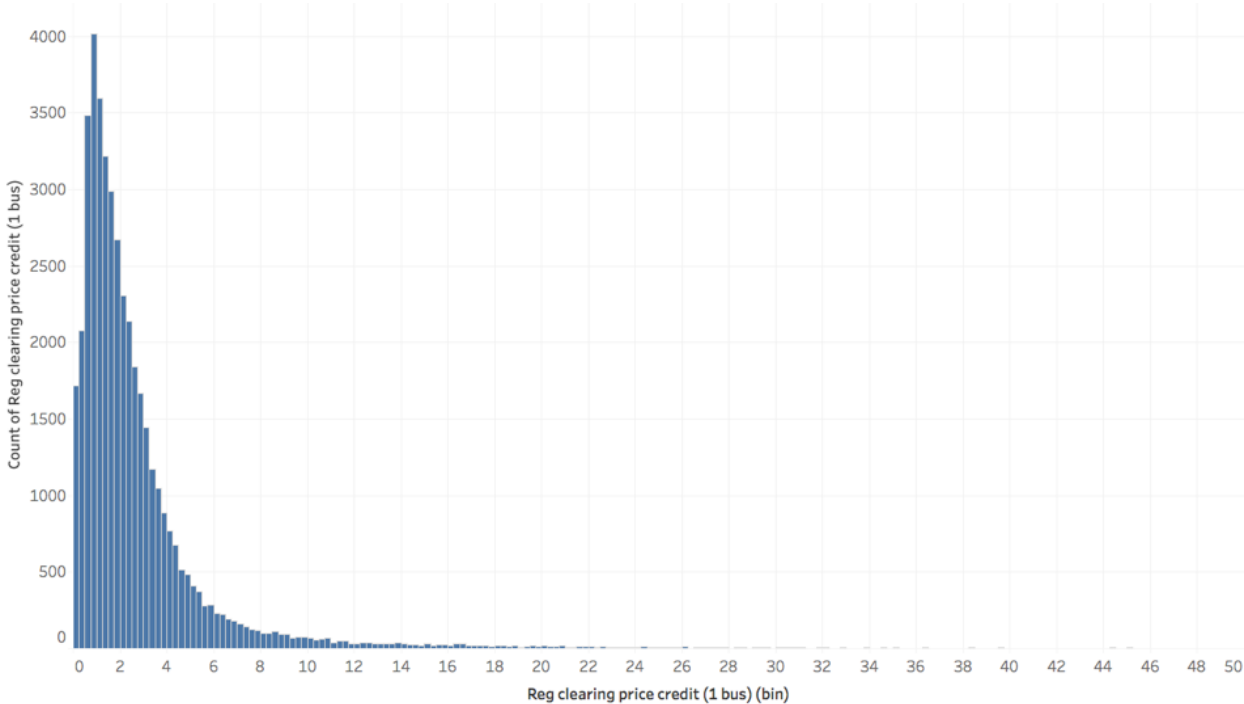


Figure 57. Histogram of the Regulation Clearing Price Credits for the case of one representative electric bus.

