Developing Sustainable Urban Transport System for the Metropolitan District of Quito

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Disclaimer

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The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

Abbreviations & Acronyms

ATD	Average Travel Distance
BCA	Benefit-Cost Analysis
BRT	Bus Rapid Transit
CER	Certified Emissions Reduction
CHQ	Centro Histórico de Quito
CPI	Consumer Price Index
EMSAT	Metropolitan Transport Services and Administration Company
EPMMQ	Quito Metropolitan Public Metro Company
IBRD	International Bank for Reconstruction and Development
ITS	Intelligent Transport System
LRT	Light Rail Transit
MDQ	Metropolitan District of Quito
MDMQ	Municipality of the Metropolitan District of Quito
NPV	Net Present Value
PLMQ	Quito Metro Line One Project
PPHPD	Passengers per Hour per Direction
PV	Present Value
SCC	Social Cost of Carbon
SITP	Integrated Mass Transit System
TRB	Transportation Research Board
VOC	Vehicle Operating Costs
VTT	Value of Travel Time
VTTS	Value of Travel Time Savings

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EXECUTIVE SUMMARY

The Metropolitan District of Quito (MDQ) is undergoing a twofold transport-related policy challenge. For one, rapid urbanization and population growth is causing a surge of daily transport demand and triggering a severe traffic congestion problem. Simultaneously, slightly more than half of the MDQ's carbon emissions are coming from transport sources. This is exacerbating the negative effects of climate change on the city including water stress and forest fires.

To respond to this major policy issue, the Municipality of the Metropolitan District of Quito (MDMQ) began the construction of a 23-kilometer-long underground metro system under the Quito Metro Line One Project (PLMQ). The World Bank has been supporting this initiative by loaning $205 million to the MDMQ in the hopes of generating economic and environmental benefits through this sustainable urban transportation system.

In this report, I look into three policy alternatives that the MDMQ and the World Bank could adopt given this situation. Option I is to let present trends continue and keep the PLMQ. Option II is to replace the PLMQ with a light rail transit (LRT) system, building LRT tracks on the PLMQ route. Option III is to expand the MDQ's existing bus rapid transit (BRT) Metrobus-Q network to the suburban areas, opening up four new routes that are on average 20 kilometers long. All these policy alternatives are evaluated using a full-scale benefit-cost analysis. Other evaluative criteria include equity, feasibility of implementation, and feasibility of administration.

Ultimately, I recommend Option I to let present trends continue and keep the PLMQ. But the PLMQ is limited in its ability to address the suburban accessibility issue. Therefore, the MDMQ and the World Bank may consider adopting Option III to expand the BRT system to the suburban areas once the implementation of Option I is completed.

In implementing this recommendation, the MDMQ and the World Bank should focus on enhancing the PLMQ's transparency and accessibility as well as mitigating the PLMQ's possible negative impacts on the city's environment and historic heritage. The two organizations should also look into a more long-term financing scheme to ensure the project's financial sustainability. In addition, equipping the metro with intelligent transport system to maximize efficiency could be worth exploring if conditions permit.

PROBLEM DEFINITION

Problem Statement

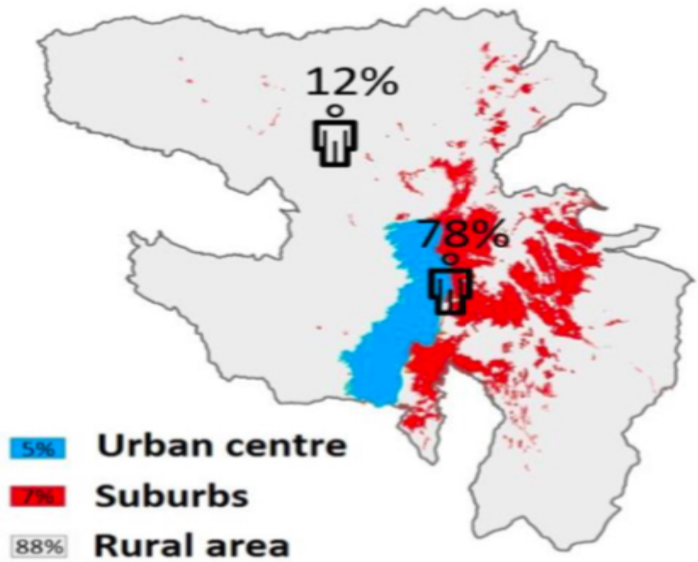
The rapidly developing Quito Metropolitan District is suffering from severe traffic congestion issue. Meanwhile, 52 percent of the city's carbon emissions are coming from transport sources, which is too much.

Background of the Problem

High Population Density

The Metropolitan District of Quito (MDQ) is located within Pichincha Province, Ecuador and is dividable into urban center, suburbs, and rural areas. The MDQ is approximately 423,000 hectares, but the urban center and surrounding suburban areas take up only 12 percent of this total area (Alvear et al., 2016). However, according to Alvear et al., around 78 percent of the MDQ's roughly 2.72 million population resides within this proportionately small and long-shaped urban area that stretches across the valley. This means that Quito has a relatively high urban population density. See Figure 1 for land and population distribution of the MDQ.

Figure 1: Land and Population Distribution of Quito



Source: Adapted from Alvear et al., 2016.

Worsening Traffic Congestion

Quito is facing a major traffic congestion problem because on top of this already high population density, the MDQ's population has been growing explosively. This is precipitating an unprecedented rise in transport demand and challenging Quito's traffic situation. According to Jonker (2016), the MDQ has been growing at an average rate of 37,000 residents or 1.7 percent per year. This is primarily due to a high inflow of immigrants – roughly 11,400 people per year – from other parts of the country (Jonker, 2016). Transport demand has mirrored this trend. Car ownership in Quito and Ecuador at large is rising annually by 5.6 percent, compared to most developed countries' annual average of 1-2 percent (Roque, & Masoumi, 2015).

But the MDQ's transport infrastructure has not been able to handle this increase. Traffic congestion is therefore on the rise. In a survey conducted by Herrera et al. (2016), over 72 percent of respondents identified Quito's vehicular traffic as one of the most important problems for the city. Herrera et al. also discovered that a person in Quito spent on average

2.02 hours daily for transport in 2015. This relatively high value suggests that there is a need for better public transport system that can accommodate the city's burgeoning population and movements. Such severe degree of traffic congestion translates into undesirable socioeconomic consequences such as loss of productivity.

Carbon Emissions and Climate Change

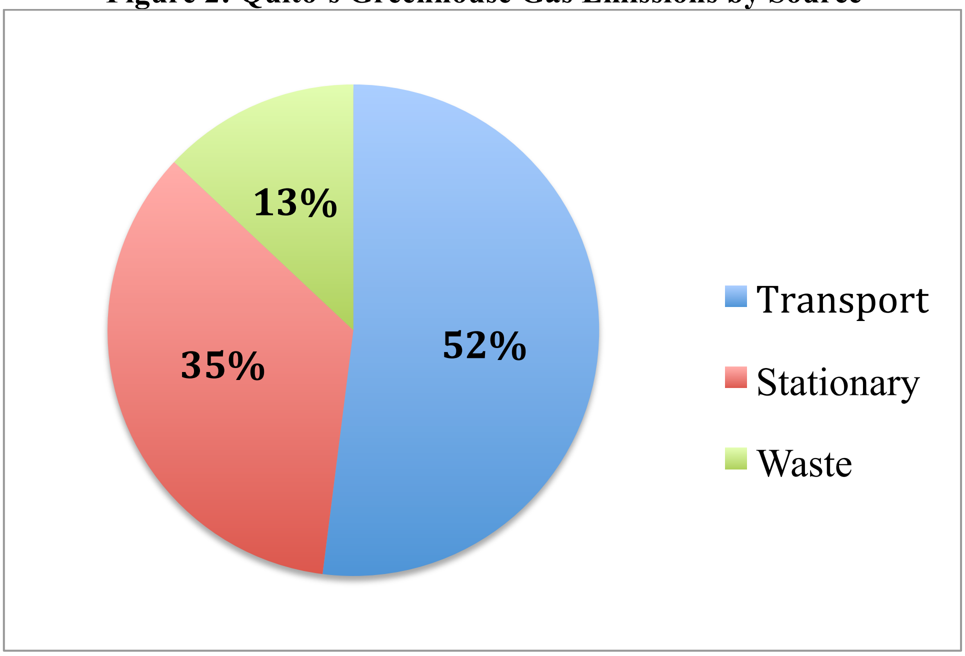
Meanwhile, Quito faces a huge climate change issue to which the city's transport system is related. In the last century, the MDQ's average temperature has increased by 1.2°C while rainfall has decreased by 8mm per decade during the same period (Zambrano-Barragan et al., 2010). This combination of increasing temperature and decreasing precipitation may worsen the MDQ's water stress, which is already a major policy concern because of increasing population and water consumption.

Moreno (2010) pointed out that the MDQ is actually experiencing challenges in drawing water from nearby sources as Quito's endemic ecosystem is drying up and losing its capacity to store water. This has forced the MDQ to constantly move its principal water source to more distant locations. According to Moreno, in 1957, the majority of the MDQ's water and sewerage utilities relied on a source located at El Placer, 24 kilometers away from the city. Since 2001, however, the MDQ has been drawing most of its water from Papallacta Ramal Norte, 73 kilometers away. Moreno estimated that, if present trends continue, it is likely that the MDQ may have to move its water source yet again to Ríos Orientales, over 110 kilometers away from the city.

In addition, glaciers around Quito, which supply on average 15.4 percent of the MDQ's water during the drought season between November and February, are disappearing due to climate change (Buytaert et al., 2017). All these phenomena are making the city more vulnerable to water stress. Rising temperatures are also increasing Quito's susceptibility to forest fires, which is deemed "extremely serious" by C40 Cities Climate Leadership Group [C40] (2018).

Fifty-two percent of carbon emissions of the MDQ come from transport sources as shown in Figure 2 (C40, 2018). Moreover, traffic congestion tends to increase greenhouse gas emissions. Given these facts, there is an urgency to act to mitigate the city transport's exacerbating effects on climate change.

Figure 2: Quito's Greenhouse Gas Emissions by Source



Source: C40, 2018.

Important Associated Factors

Historical Landscape

Quito is a city of rich history and was inscribed on the UNESCO World Heritage List in 1978 along with the Polish city of Krakow. It was the first Latin American city to receive such international recognition and is widely considered to have the "best-preserved historic Centre and least altered of Latin America" (Medina, 2013). The City of Quito's historic center, Centro Histórico de Quito (CHQ), is located at the heart of MDQ and displays a unique Spanish colonial urban layout that has changed little since its construction in the 16th century. The CHQ is protected under several layers of international, national, and local laws and regulations (Medina, 2016) and any transport policy alternative should put the preservation of Quito's heritage into consideration.

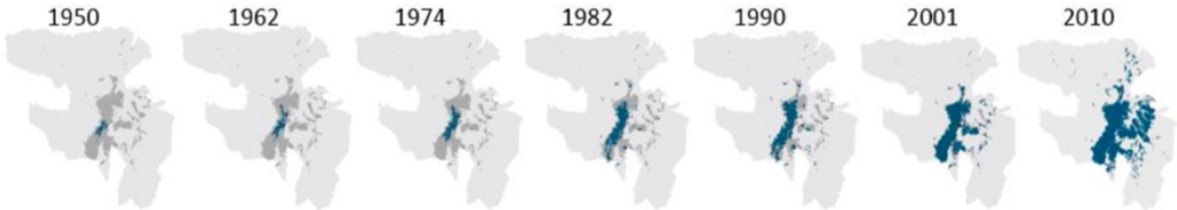
Earthquake Resiliency

Another important consideration is earthquake resiliency. Earthquakes are rather frequent in Ecuador because the country sits on the Pacific Ring of Fire with constant and active volcano and earthquake activities. Though the most devastating earthquakes in recent years have affected the coastal areas west of the capital city, noteworthy earthquakes with magnitudes of 4 or above have been becoming more frequent since 2016 (Vervaeck, 2018). It is therefore important to consider future possibilities of heightened earthquake activities near the MDQ, and their implications for future transport policy development. Infrastructures that are structurally more vulnerable to earthquakes than others are less likely to address this particular safety concern that Quito has.

Transport Inclusivity

Promoting urban transport inclusivity is also an important factor to consider, particularly with respect to the suburban areas. The MDQ's suburbs are expanding at a speedy rate, as shown in Figure 3.

Figure 3: MDQ's Suburban Expansion Over Time

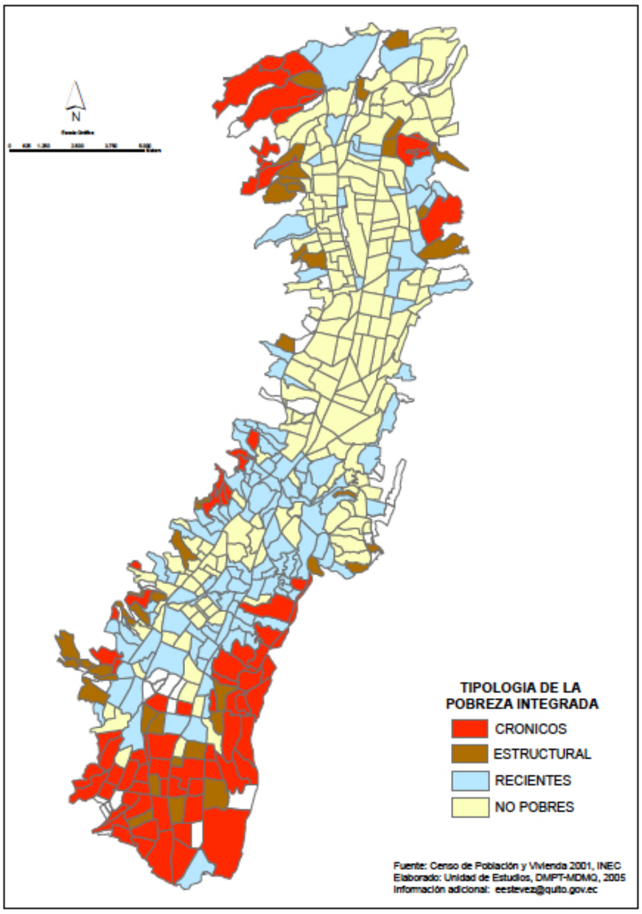


Source: Adapted from Alvear et al., 2016.

Along with this expansion, these areas are seeing even more rapid population growth than the urban center. This is because Quito's unique geographic restriction of being on a narrow valley creates huge housing poverty issue, compelling many to commute from the suburbs to the urban center (Alova, & Burgess, 2017). Traffic conditions between the two are hence under immense pressure. The best example is the Guayasamín Tunnel, which is one of the busiest points of entry into the urban center from the suburbs. The tunnel is currently accommodating about 34,000 vehicles daily compared to 24,000 for which it was originally designed (Magdaleno, 2016). Ensuring that this suburban population is not left out from future transport improvements would be crucial for social inclusion and balanced urban development.

This notion of inclusivity also applies to the economically disenfranchised communities of the urban center. As shown in Figure 4, Quito's urban poor live on the edges of the valley, mostly removed from key transport routes that pass through areas that are wealthier and closer to the city's geographic center. Members of the low-income communities depend heavily on public transport to access employment opportunities, education, and health services. Preventing this impoverished population from transport exclusion would therefore be vital for the MDQ's general welfare and equity.

Figure 4: Distribution of Poverty within Quito's Urban Center



Source: Adapted from Stein, 2011.
Notes: The intensity of urban poverty decreases as it moves from areas colored in red – indicating the highest poverty rate – to areas colored in light yellow indicating the lowest poverty rate.

Recent Response

The Ecuadorian government has been pushing for reducing greenhouse gas emissions, primarily by increasing hydropower usage for energy generation. But it has also been subsidizing gasoline and diesel, which has increased fossil fuel consumption by the transport sector dramatically (Jakob, 2017). Some have suggested that the Ecuadorian government should reduce or eliminate these subsidies as well as adopting the carbon tax. This could bolster a modal shift from automobiles to more environmentally sustainable modes of public transport (Jakob, 2017).

Meanwhile, the Municipality of the Metropolitan District of Quito (MDMQ), the MDQ's governing body, has been trying to resolve these negative consequences of traffic congestion by soliciting help and financial assistance from international organizations, namely the World Bank.

REVIEW OF LITERATURE

Introduction of the Literature Review

Many municipalities of developing countries, as is the case with Quito, are experiencing transport-related policy challenges. Due to burgeoning population and economic activities from rapid urbanization, these areas are suffering from problems including but not limited to congestion, traffic accidents, pollution, climate change, and lack of accessibility for the impoverished urban community. In this literature review, I look into the nature of sustainable urban transport development and compare three possible problem solutions to one another. These solutions are 1) road-based public transport, 2) rail-based public transport, and 3) non-motorized vehicles, possibly combined with greater system efficiency.

Nature of Sustainable Urban Transport Development

Scholars have suggested that developing a sustainable urban transportation system would be a solution to increasing transport-related problems in developing cities. According to Black et al. (2002), sustainable urban transport is a system that 1) provides access to goods and services efficiently for every resident of the area, 2) protects the environment, cultural heritage, and ecosystems for the present generation, and 3) does not deprive future generations of the opportunities to reach at least the same welfare as those living now. Black et al. further pointed out that the sub-objectives of economic efficiency, inhabitable streets and neighborhoods, environmental protection, equity and social inclusion, safety, and contribution to economic growth must be met. This indicates that sustainable development is not simple but has a complex nature. Litman and Burwell (2006) also argued that sustainable urban transport should be balanced in its objectives, pushing for socioeconomic and environmental goals at the same time.

Possible Solutions

Road-Based Public Transport

For most cities, road-based public transport, mainly buses, is the only available modes of public transportation. However, many bus systems are unreliable and insufficient in serving the needs of growing cities and meeting the expectations of residents (Verma, Verma, P., & Sindhe, 2013). This could precipitate increases in automobile ownership and usage. Therefore, most literature on road-based public transport is about Bus Rapid Transit (BRT) system that mirrors rail transit's amenities and performance.

Many of these studies support the positive impacts of BRT on sustainable urban traffic. Carrigan, King, Velasquez, Raifman, and Duduta (2013) discovered several benefits of BRT adoption, the most notable gain coming from travel time savings; they found that infrastructures for accelerated boarding, segregated bus lanes, and other design features of the BRT allow cities to cut waiting and in-vehicle times significantly for both BRT and non-BRT users. Carrigan et al. also discovered that BRT reduces greenhouse gas emissions by reducing vehicle-kilometers traveled and enhancing the buses' fuel efficiency. This particular environmental effect was also noted by Turner, Kooshian, and Winkelman (2012), who observed that the Colombian capital Bogota reduced its CO_2 emissions by 1 million tons per year after adopting its BRT system TransMilenio and new fuel quality regulations. Another positive environmental impact was the improvement of overall air quality. Bogota, for example, reported a reduction of SO_2, NO_X, and particulate matter by 43, 18, and 12 percent respectively (Turner et al., 2012). Other BRT benefits involved the enhancement of public safety through decline in traffic accidents (Goh, Currie, Sarvi, & Logan, 2013), and higher land and property values through increased urban development (Cervero & Kang, 2011).

However, there are slight disagreements between literatures regarding the prospects of BRT relative to rail transit. According to Pojani and Stead (2015), BRT can be built at considerably lower costs of under $8 million per kilometer compared to rail and has more rapid implementation times of less than five years. However, Pojani and Stead also pointed out that the public usually perceives the BRT system to be the second-best mode after rail due to its early challenges in terms of implementation and funding. In contrast, Cervero (2013) presented a more optimistic perspective towards BRT, arguing that rail versus bus is an incorrect dichotomy; he argued that BRT could offer greater operational flexibility and quality of service, and is particularly better suited for low-density settings.

Rail-Based Public Transport

Much of the literature regarding rail-based public transport differentiated Light Rail Transit (LRT) systems – designed to perform somewhere between conventional buses and a metro – from heavy rails and metro systems. But both rail-based systems have a clear advantage over road-based public transport in that carbon and pollutant emissions from railways are generally much smaller than those of road-based vehicles. The UN-Habitat's 2013 report estimated BRT's emissions levels to be 28-204 grams per passenger kilometers; its estimates for those of LRT and metro were 38-100 grams and 38-68 grams per passenger kilometers respectively.

However, there are disadvantages of rail-based transport and the biggest one is that they are highly costly. Capital costs for LRT are about $20-40 million and $50-150 million for metro depending on project type and scale, in contrast to BRT and regular bus systems' $5-15 million according to the report. With respect to LRT specifically, the system once possessed clear edge over road-based public transport to offset some of this cost disadvantage. According to Gwilliam (2002), LRT generally used to have greater carrying capacity than buses, but Pojani and Stead (2015) pointed out that much of the gap between LRT and buses has been closed by BRT's technological advancements. For metro, besides the fact that it is the most costly urban transport option, there are extenuating environmental concerns as well. Although it is generally true that transport construction emissions of carbon and pollutants are not significant given their long-run environmental returns, tunneling operations for underground metro networks can create huge emissions issues (Asian Development Bank, 2010). Hence, pursuing rail-based urban transport would require enough population density and demand to justify the substantial financial investment that a city needs to make for adopting it.

Non-Motorized Vehicles

Bikes are very common modes of urban transport in developing cities especially in Africa and Asia as well in some developed cities with strong supportive policies that encourage bike usage for environmental reasons (Servaas, 2000). Particularly in the developing world, they are employed by a big portion of the population who prefer high time costs to high financial costs for transport (Dimitriou & Gakenheimer, 2012). But according to Pojani and Stead (2015), politicians of the developing world disfavor non-motorized modes of transport because they see them as signs of backwardness and they instead divert most of governmental support to motorized vehicles. Pojani and Stead suggested, however, that many Chinese and Latin American cities have recently started to implement policies that seem to increase non-motorized transport including e-bike national standards, local sale restrictions of gasoline scooters, and prohibition of motor vehicles in many urban districts. Bike sharing programs were also discussed as a policy encouraging modal shift, but empirical evidence suggested that whereas it does increase bike usage, it did not seem to decrease motor vehicles usage (Midgley, 2011).

System Efficiency

Along with the three modes of transport discussed, greater system efficiency would further enhance sustainability. Possible measures to improve system efficiency are various, including Intelligent Transport System (Sussman, 2005) and pricing mechanisms. For small and medium-sized cities with low administrative capacity, relatively easily enforceable fuel taxes may be employed, while larger cities may employ cordon pricing and direct road charges to reduce peak-congestion (Timilsina, & Dulal, 2008).

Policy Alternatives

Option I: Let Present Trends Continue and Keep the Quito Metro Line One Project (PLMQ)

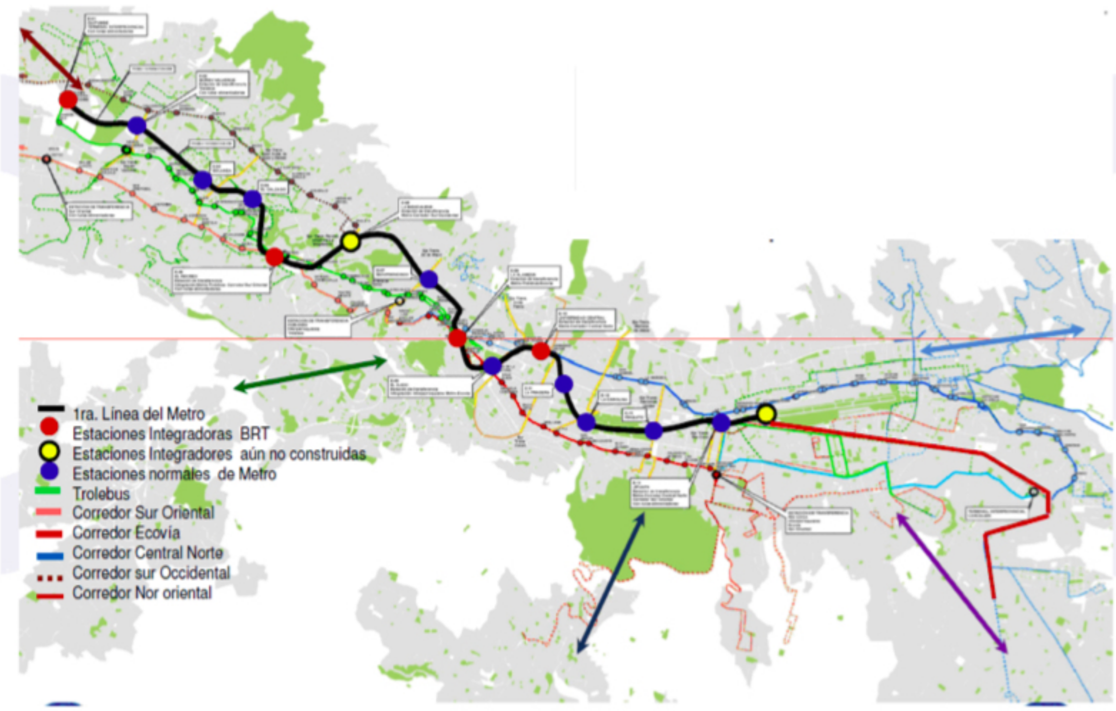
As identified in the literature review, a metro system is highly capable of transporting more than 300,000 passengers daily. For a city like Quito with more than 2 million population, it may be possible to justify the huge cost in constructing the underground infrastructure.

As of now, a 23-kilometer-long underground metro of 15 stations is being constructed under the Quito Metro Line One Project (PLMQ). The PLMQ is being implemented by the Quito Metropolitan Public Metro Company (EPMMQ), which was created in April 2012 as a city-owned enterprise. The total cost of the project is estimated to be around $1.684 trillion of which $205 million is financed by the World Bank Group in loans (International Bank for Reconstruction and Development [IBRD], 2013). The MDQ is planning on linking this new metro system with existing BRT systems as part of its Integrated Mass Transit System (SITP) as shown in Figure 5.

According to the IBRD (2013), the current BRT system cannot be expanded within the urban center to meet the dramatic future increases in ridership, especially on the corridor that passes through the narrow bottleneck of the CHQ. The IBRD estimated that the ridership on this corridor is going to surge from 14,000 passengers per hour per direction (pphpd) in 2013 to 23,000 pphpd by 2020. Based on this rationale, the MDQ is aiming its new metro to be able to accommodate 23,000 pphpd.

If the IBRD's ridership projection were accurate, then an underground metro of such transport capacity would be a viable and effective solution to the BRT's incapacity to handle explosive growth in ridership. It would also solve the traffic problem without demolishing the historical landscape and buildings of the CHQ. Hence, continuing this initiative and letting present trends continue may be a suitable policy alternative for this particular issue.

Figure 5: Proposed Integrated Mass Transit System (SITP)



Source: Adapted from IBRD Project Appraisal Document, 2013.

Option II: Implement the Light Rail Transit (LRT) System

Rail-based public transport tends to be friendlier to the environment than road-based transport in terms of carbon emissions. At the same time, compared to an underground metro, LRT is more affordable, generally less invasive of existing infrastructure and ecosystem, and more likely to fulfill the benefit-cost justification. As Calgary's LRT system shows (see Figure 6), LRT is not invasive towards existing road structures and can be highly adaptable. If a situation makes construction of LRT tracks on the existing roads difficult, it could also be operated on a narrow elevated passageway, as shown by the example of Singapore (see Figure 7).

Figure 6: Light Rail Transit (LRT) System in Calgary, Canada

Source: Rail for the Valley, 2011.

Figure 7: Light Rail Transit (LRT) System on Elevated Passageways in Singapore

Source: Rail for the Valley, 2011.

Laying the LRT tracks on the existing planned PLMQ tracks may not only increase Quito's transport capacity, but also allow the MDQ to avoid possible unmanageable pollution from underground metro construction as discussed in the literature review. Therefore, the MDQ and the World Bank may consider adopting the LRT system instead of a metro to develop sustainable urban transport.

Option III: Expand Existing Bus Rapid Transit (BRT) System to the Suburban Areas

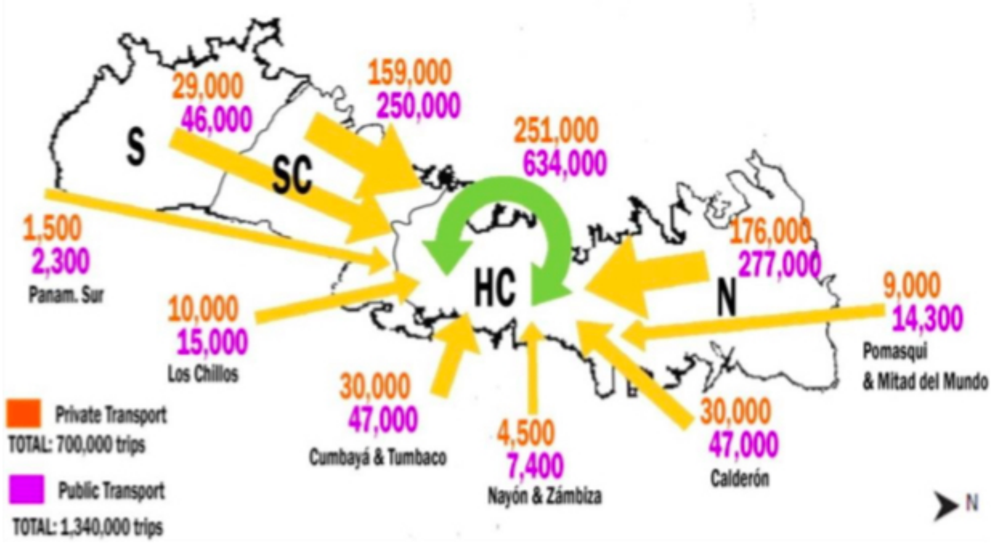
The MDQ currently has a vibrant BRT system known as Metrobus-Q that is approximately 83.8 kilometers in total system length and comprised of three corridors: Trolebús, Ecovía, and Occidental commenced in 1995, 2002, and 2005 respectively (Global BRT Data, 2018). After significant refurbishments between 2010 and 2012, Metrobus-Q now serves over 828,000 passengers a day and facilitates on average 9,880 trips per kilometer – this is 110 percent higher than Washington, D.C. Metro's 4,600 trips per kilometer (IBRD, 2013). As shown in Figure 8, Metrobus-Q is able to ensure timely and reliable trips through BRT-exclusive lanes. Its stations are aligned to the center of the road to make transfers convenient.

Figure 8: Metrobus-Q Operations

Source: Karl Fjellstrom, Far East Mobility, 2008.

However, while the current BRT network may seem sufficient, there are about 1.8 million trips made daily in the MDQ using over 2,500 non-BRT buses (IBRD, 2013). These non-BRT buses tend to impose much longer travel times on passengers due to their lack of exclusive lanes. This inefficient dependence on non-BRT buses occurs predominately in the southern tip of the valley with high poverty rate as well as in the suburbs from which huge daily trips to the CHQ – over 218,000 in 2009 (Jarrín Silva, 2014) – are made (see Figure 9).

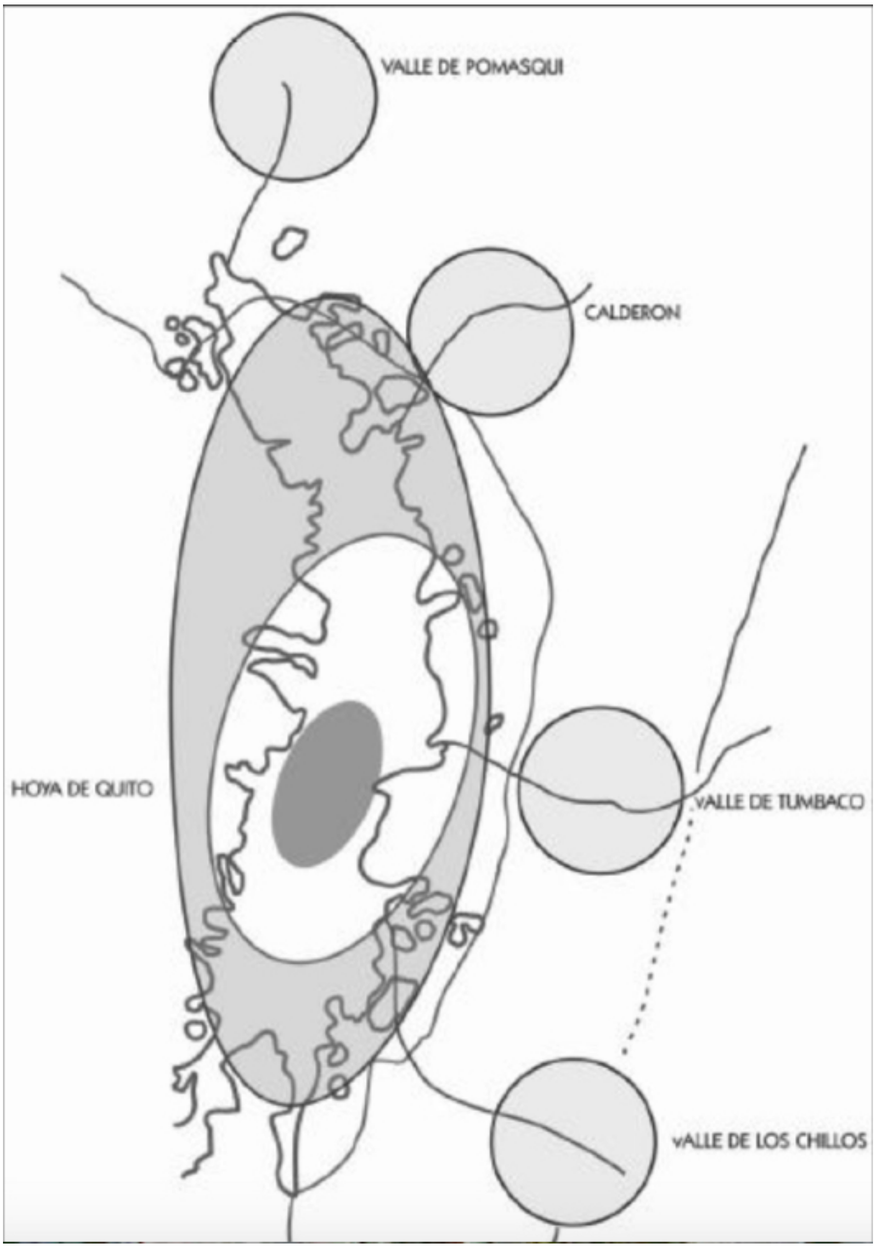
Figure 9: Number of Motorized Trips per Day to the CHQ from the Suburbs (2009)



Source: Adapted from Jarrín Silva, 2014.

A possible policy alternative would be expanding the BRT network to these underserved areas and suburbs. The MDQ and the World Bank may consider creating new Metrobus-Q routes that connect the CHQ to four major suburban population centers of Pomasqui, Calderón, Tumbaco, and Valle de Los Chillos (see Figure 10). According to my estimates derived using Google Maps, the average length of these new four BRT corridors would be approximately 20 kilometers. These new additions to the BRT network could shorten the duration of trip between each suburban center and the CHQ and help counter the traffic congestion problem.

Figure 10: Possible BRT Routes to Four Neighboring Suburban Areas



Source: Adapted from Jarrín Silva, 2014.

EVALUATIVE CRITERIA

Benefit-Cost Analysis

The Benefit-Cost Analysis (BCA) is a widely employed systematic approach to evaluate the strengths and weaknesses of a policy alternative. It measures both benefits and costs that the alternative could generate over a specified period of time, expresses them in monetary terms, and adjusts them using the time value of money to derive the net present value (NPV). Major infrastructure projects that involve substantial financial investments, such as the PLMQ, often require the BCA. The purpose of this is to verify whether their benefits would outweigh their costs and by how much. A positive net present value would usually justify the investments.

The BCA for this particular set of policy alternatives would estimate how much traffic and environmental benefits an alternative could generate for the residents of the MDQ while minimizing initial financial input and other associated costs.

Methodology Part I: Benefit and Cost Categories

I will conduct the BCA using a time period of 20 years and the following methodology. See Figures 11 and 12 for benefit and cost categories that I will use for the analysis.

Figure 11: Benefit Categories

Benefit Category	Specification
Value of Travel Time Savings (VTTS) from Bus Travel	Daily (Metro/LRT/BRT) Trips * Percentage of (M/L/B) Passengers Diverted from Buses * Average Hours Saved * 365 * Value of Travel Time (VTT)
VTTS from Other Motorized Travel	Daily (Metro/LRT/BRT) Trips * Percentage of (M/L/B) Passengers Diverted from Private Vehicles * Average Hours Saved * 365 * VTT
VTTS through Reduced Congestion	MDQ Population * Average Travel Time Spent on Congestion * Anticipated Congestion Reduction Rate of (Metro/LRT) * VTT
Reduced Vehicle Operating Costs (VOC) for Public Transport	[Daily (Metro/LRT/BRT) Trips * Percentage of (M/L/B) Passengers Diverted from Buses * Average Travel Distance (ATD) for Buses * 365 * VOC for Public Transport] / Average Bus Capacity
Reduced VOC for Private Surface Vehicles	[Daily (Metro/LRT/BRT) Trips * Percentage of (M/L/B) Passengers Diverted from Private Vehicles * ATD for Private Vehicles * 365 * VOC for Private Transport] / Average Occupancy Rate for Cars
Environmental Benefits	Annual Carbon Emissions Reduction of (Metro/LRT/BRT) * Social Cost of Carbon (SCC)

Figure 12: Cost Categories

Cost Category	Specification
Capital Costs	Capital Costs for Land Purchases, Construction, Non-Vehicle Equipment, etc.
Train Set Costs	Acquisition Costs per Train * Number of Trains
Operating Costs	Costs of Annual Operations
Station Services Costs	Annual Station Services Costs per Station * Number of Stations

Unlike those of Option I and Option II, Option III's BCA will not consider VTTS through reduced congestion as a benefit. This is because there is no reliable estimate for how much congestion the extended Metrobus-Q network could reduce in contrast to the available information on how much congestion the PLMQ could reduce. It is also very likely that BRT's characteristic of being built on existing roads would prevent it from mitigating congestion as much as the metro or LRT. Even if there were some congestion reduction benefits from extending the BRT network to the suburbs, these benefits would likely be offset by increases in congestion near the CHQ due to the convergence of the four new BRT routes.

Furthermore, Option III BCA's cost categories will not include train set costs, operating costs, and station services costs. The four new BRT corridors are most likely to absorb the existing non-BRT bus services with similar operating and station maintenance costs. Hence, capital costs would be sufficient for conducting BCA on Option III.

Methodology Part II: Key BCA Standard Rates and Values

In the meantime, the following (see Figure 13) are the key standard values that I will apply across all three alternatives for discount rate, annual trip increase rate, value of travel time (VTT), vehicle operating costs (VOC), average travel distance (ATD), maximum bus capacity, average passenger vehicle occupancy rate, and social cost of carbon (SCC).

Figure 13: Key BCA Standard Rates and Values

Rate and Value Name	Numerical Value	Source/Justification
Discount Rate	5 Percent	Lopez (2008); Schueuren (2011)
Annual Trip Increase Rate	1.7 Percent	IBRD (2013)
Percentage of (Metro/LRT/BRT) Passengers Diverted from Buses	85 Percent	IBRD (2013)
Percentage of (Metro/LRT/BRT) Passengers Diverted from Private Vehicles	10 Percent	IBRD (2013)
Percentage of Induced Demand	5 Percent	IBRD (2013)
Value of Travel Time (VTT): Public Transport	$2.48	IBRD (2013)
VTT: Private Transport	$5.87	IBRD (2013)
Vehicle Operating Costs (VOC): Public Transport	$0.22	IBRD (2013)
VOC: Private Transport	$1.24	IBRD (2013)
Average Travel Distance (ATD): Public Transport	9.8 Kilometers	IBRD (2013)
ATD: Private Transport	16.3 Kilometers	IBRD (2013)
Maximum Bus Capacity	174 Passengers	Global BRT Data (2018)
Average Passenger Vehicle Occupancy Rate	1.9 Passengers	Sander, Mira-Salama, & Feuerbacher (2015)
Social Cost of Carbon (SCC)	$14.69	EPA (2017)

Discount Rate

Whereas the World Bank typically uses a 12 percent discount rate for Bank-funded projects, I will apply a 5 percent discount rate. This is because municipal governments like the MDMQ usually have relatively low bond rates of below 3-4 percent, and a 12 percent rate would be too high in this circumstance. This approach is consistent with Lopez (2008)'s argument that social discount rate in Latin America should be 3-4 percent based on past economic growth. Lopez added that if we take improvements in past performance into account as well, the rate should be 5-7 percent. Schueuren (2011) also suggested that economic development organizations apply a discount rate of 4-5 percent.

Annual Trip Increase Rate

There is no available literature or research study on the relationship between population increase and transport ridership increase, especially in the Latin American and Ecuadorian context. For this BCA, I will assume a proportional relationship between annual population increase rate and annual trip increase rate, and apply a 1.7 percent rate.

Percentage of (Metro/LRT/BRT) Passengers From Buses, Private Vehicles, and Induced Demand

These percentage values are from the World Bank's estimates (IBRD, 2013). No better estimates could be found.

VTT

In addition, I will use $2.48 and $5.87 as my VTT for Quito residents using public and private modes of transportation respectively. Distinguishing the two is consistent with the World Bank's assumption that most public transport users in Quito are in the three lower quintiles of income distribution while most private vehicle users are in the fourth and fifth quintiles (IBRD, 2013).

In generating these two VTT, I followed the World Bank's estimation that almost 80 percent of projected time saving benefits would come from commuters (IBRD, 2013). Based on this fact, I calculated the weighted averages of CPI-adjusted 2010 values of work and leisure time for each transport type (see Figure 14). The weights were 0.8 for the value of time for work and 0.2 for the value of time for leisure. This approach is largely consistent with Gwilliam (1997)'s recommendation to treat VTT for work and leisure separately from each other based on empirical data.

Figure 14: Generating VTT Using the World Bank's 2010 Estimation of Value of One Hour in Quito

	Leisure (0.2)	Work (0.8)	CPI-Adjusted Weighted Averages
Public Transport	$0.57	$2.54	$2.48
Private Transport	$1.36	$6.03	$5.87

Source: IBRD, 2013.

VOC and ATD

For VOC and ATD, I directly adopted the World Bank's estimates. I then adjusted the VOC for public and private modes of transportation for inflation using CPI.

Maximum Bus Capacity

The reason for using maximum bus capacity instead of average bus capacity to calculate public transport VOC reduction is to account for the fact that public transport supply is not as elastic as private transport supply. Moreover, the sheer range between the lowest value and the highest value of bus capacity in the MDQ and the lack of comprehensive data make it challenging to use average bus capacity. According to the Global BRT Data (2018), the maximum bus capacity in the MDQ is 174 passengers.

Average Passenger Vehicle Occupancy Rate

This average passenger vehicle occupancy rate of 1.9 passengers per car is based on Sander, Mira-Salama, and Feuerbacher (2015)'s study regarding transport and air pollution in Cuenca, Ecuador. The underlying assumption is that Cuenca and Quito's rates would be reasonably similar to each other as both of them are population hubs of the same country.

SCC

I made a major departure from the World Bank's methodology by deciding to use the Environmental Protection Agency (EPA)'s SCC instead of Certified Emissions Reduction (CER) market price. Since the World Bank's 2013 project appraisal document set the value of a metric ton of carbon at $15 (IBRD, 2013), the CER market price has plummeted to near zero. This renders the World Bank's carbon price of $15 per metric ton no longer applicable. The EPA's SCC not only replaces this number, but also better reflects the overall societal damages that carbon emissions impose on a global scale.

I selected the SCC for 5 percent average discount rate, which was $12 in 2007 dollars (EPA, 2017). I CPI-adjusted this value to 2018 dollars, resulting in $14.69.

Equity

Providing transport services to every resident of an urban area is an important component of sustainable urban transport. This criterion will measure 1) an alternative's affordability and 2) its accessibility. In terms of affordability, I will compare the three alternatives' fares.

Regarding accessibility, I will try to determine if the usage of a given alternative would involve all districts evenly. Specifically, I will estimate and compare the number of people and households that would be in walking distance of each of the alternatives both within the urban center and in the suburbs. I will apply 0.25 miles (roughly 400 meters), which is the distance that is frequently used in U.S. transport research studies (Yang & Diez-Roux, 2012), as walking distance. The limited availability of research on walking distance for different trips across different population groups makes this the most compelling standard to apply.

Feasibility

Even if an alternative fulfills both the BCA and equity criteria, it cannot be a preferable one if its implementation is constrained due to the lack of political support or presence of sheer natural obstacles. It would also not be prudent to recommend an alternative if its administration after implementation would be so challenging that it would overly burden the administrative entities, which in this case are the MDMQ and the EPMMQ.

Therefore, under this criterion, I will first assess the level of political and societal support the alternatives could garner and evaluate if there are any major natural or human factors that could hinder their adoption. Elements to consider for this assessment include:

- Quito's public opinion on each alternatives
- The MDMQ officials' known political preferences
- The three alternatives' likely relationship with Quito and the CHQ's landscape, city planning, and geographic and geologic conditions
- The three alternatives' earthquake resiliency

Using these assessments, I will determine how feasible it would be for the alternative to be implemented.

Then I will measure the administrative feasibility of the alternatives and see whether the MDQ would be able to effectively manage the alternatives if they were implemented. For this, I will look into the MDQ's governing structure, general administrative capacity, and prior experiences of public transport management.

OUTCOMES MATRIX

Criteria and Sub-Criteria	Option I: Let Present Trends Continue and Keep the PLMQ	Option II: Implement the Light Rail Transit (LRT) System	Option III: Expand the Bus Rapid Transit (BRT) System to the Suburban Areas
Benefit-Cost Analysis	**$500 Million NPV**	**$519 Million NPV**	**$291 Million NPV**
Transport Benefits	$3,136 Million PV	$1,547 Million PV	$921 Million PV
Annual Amount of Carbon Reduction	67,000 Metric Tons ($13 Million PV)	67,000 Metric Tons ($13 Million PV)	80,400 Metric Tons ($15 Million PV)
Equity	**Moderate**	**Moderate**	**High**
Affordability	$0.45 Fare	$0.25 Fare	$0.25 Fare
Urban Accessibility	92.7 Percent of Households in Walking Distance	92.7 Percent of Households in Walking Distance	Peripheral Neighborhoods Likely to Benefit
Suburban Accessibility	Minimal Improvement	Minimal Improvement	At Least 100,000 + Suburban Residents Served
Feasibility of Implementation	**High**	**Low**	**Moderate**
Feasibility of Administration	**High**	**High**	**Low**

Note: Main evaluative criteria discussed in the previous section are bolded and italicized. Sub-criteria are neither bolded nor italicized.

Analysis

Option I: Let Present Trends Continue and Keep the PLMQ

Benefit-Cost Analysis

The BCA for this policy alternative relied on the following alternative-specific rates and values that were CPI-adjusted or multiplied by population increase rate (see Figure 15).

Figure 15: Specific Rates and Values for Option I BCA

Rate and Value Name	Numerical Value	Source/Justification
Total Daily Metro Trips in Quito in 2019	295,000 Trips	IBRD (2013)
Average Travel Times Saved for Average Bus Trip	0.323 Hour	IBRD (2013)
Average Travel Times Saved for Average Trip by Other Motorized Vehicles	0.09 Hour	IBRD (2013)
MDQ Population in 2019	2,766,240	Alvear et al (2016)
Average Annual Travel Times Spent on Congestion	31 Hours	INRIX (2017)
Anticipated Congestion Reduction Rate of Metro	4 Percent	IBRD (2013)
Anticipated Annual Carbon Emissions Reduction	67,000 Metric Tons	IBRD (2013)
Capital Costs	$1,346,052,667	IBRD (2013)
Train Set Costs	$206,010,045	IBRD (2013)
Operating Costs in 2019	$64,104,360	IBRD (2013)
Annual Station Services Costs per Station	$665,368.96	Quddus, Harris, & Graham (2007)
Number of Stations	15	IBRD (2013)

The result of this BCA using the standard and alternative-specific rates and values are as the following (see Figure 16).

Figure 16: Option I BCA Result

Categories	Value	Percentage
VTTS from Bus Travel	$1,085 Million	34.5 Percent
VTTS from Other Motorized Travel	$84 Million	2.7 Percent
VTTS through Reduced Congestion	$212 Million	6.7 Percent
Reduced VOC for Public Transport	$58 Million	1.8 Percent
Reduced VOC for Private Surface Vehicles	$1,696 Million	53.9 Percent
Environmental Benefits	$13 Million	0.4 Percent
Total PV Benefits	**$3,149 Million**	**100 Percent**
Capital Costs	-$1,346 Million	50.8 Percent
Train Set Costs	-$206 Million	7.8 Percent
Operating Costs	-$949 Million	35.8 Percent
Station Services Costs	-$148 Million	5.6 Percent
Total PV Costs	**-$2,649 Million**	**100 Percent**
NPV Benefits	**$500 Million**	**N/A**

The NPV benefits were $500 million, providing economic justification for the alternative. Transport benefits were $3,136 million in total and were much bigger than environmental benefits of $13 million.

Equity

Affordability

Quito's metro is going to be highly subsidized, which would result in low fares and high affordability. According to Osava (2016), the MDMQ expects its fare to be $0.45, which is 80 percent higher than the $0.25 Metrobus-Q fare (Numbeo, 2018). But the PLMQ scores high in terms of affordability because it would keep the share of average commuter transport spending out of average total income and spending relatively low. For the convenience of analysis, I will assume that an average PLMQ commuter would take the metro twice a day and commute all 30 days of a given month. I will also assume that the average PLMQ commuter would not rely on other modes of transport. These assumptions mean that the average PLMQ commuter would spend $27 a month.

In this scenario, considering that Quito's average monthly net salary after tax is $526.67 (Numbeo, 2018), the PLMQ would allow an average MDQ commuter to limit his or her transport spending to 5.1 percent of average monthly income. When applying the $27 hypothetical monthly PLMQ commute spending to the average monthly personal cost of living of $579.45 (Numbeo, 2018), the share of transport expenses decreases to 4.7 percent. This indicates that the option to continue with the PLMQ would be fairly affordable.

Accessibility

The integration of the metro to the Metrobus-Q network and the formation of the SITP would greatly increase Quito's urban transport accessibility for all income levels. According to the IBRD (2013), once the metro is completed, approximately 92.7 percent of the MDQ's urban households would be within 400 meters of the SITP. As of now, 66 percent of households enjoy the said accessibility.

However, this would not address any traffic congestion and accessibility issues concerning the suburban areas. Whereas some level of improvements in traffic connecting the suburbs and the CHQ might occur as a spillover of enhanced urban center traffic performance, the effect is likely to be minimal.

Thus, with moderately high affordability, high urban accessibility, and low suburban accessibility, the option to let present trends continue has overall moderate equity.

Feasibility

Feasibility of Implementation

The option scores high for feasibility of implementation. The PLMQ has strong political support on both national and municipal levels. The Ecuadorian government, even with low oil prices that are hurting its energy export-dependent economy, is showing appetite for large infrastructure projects (Emery, 2017). The MDMQ is also highly eager about the PLMQ, seeing it as a more permanent solution to traffic problems when compared to other options (Salar Khan, 2016). While there are some concerns regarding opportunity costs and possible gentrification that could negatively affect the urban poor (Osava, 2016), public opinion is generally favorable towards the PLMQ. In a survey focusing on low-income residents, for instance, over 68 percent of the respondents saw that the PLMQ would improve their lives in relation to time savings, higher comfort, better security, and reduced pollution (IBRD, 2013).

Besides the political aspects of implementation, the PLMQ has other features that make it an attractive policy alternative. Given that the CHQ is far too narrow to accommodate any further road lane, underground transport is the only realistic way to handle explosive transport demand growth on this corridor. The World Bank's appraisal document also noted that tunneling underneath the MDQ would not be too challenging and that potential environmental damages from the construction would be manageable (IBRD, 2013).

Feasibility of Administration

The MDMQ has an abundant experience of operating large public transit networks, especially Metrobus-Q. Over the years, Metrobus-Q daily ridership has dramatically increased from 400,000 to 828,000 since 2010 (IBRD, 2013) and users have expressed satisfaction with the network's high performance (Hidalgo & Graftieaux, 2007). Furthermore, the MDMQ has also successfully developed an organized feeder-trunk operation system as opposed to traditional urban transport constructed on loose affiliations and suboptimal coordination (Hidalgo & Graftieaux, 2007). These points suggest that the feasibility of administering the new underground metro system would be high.

Option II: Implement the Light Rail Transit (LRT) System

Benefit-Cost Analysis

The BCA for this policy alternative was largely similar to that of the first option. However, some of the specific rates and values were adjusted to reflect the different characteristics between underground metro and LRT systems. Due to the fact that a specific LRT plan for the MDQ does not exist, I assumed that the MDQ LRT's capacity and capital and operating costs would be around half and 40 percent of those of the PLMQ respectively. These assumptions are consistent with Wright and Fjellstrom (2003)'s study. I further assumed that the average speed of the MDQ LRT would be similar to that of the PLMQ.

For carbon emissions, I assumed that the LRT system's lower passenger capacity and its lower energy usage would offset each other, making Quito LRT's carbon reduction effect to be similar to that of the PLMQ.

Figure 17: Specific Rates and Values for Option II BCA

Rate and Value Name	Numerical Value	Source/Justification
Total Daily LRT Trips in Quito in 2019	147,500 Trips	IBRD (2013)/Half of Metro
Average Travel Times Saved for Average Bus Trip	0.323 Hour	IBRD (2013)
Average Travel Times Saved for Average Trip by Other Motorized Vehicles	0.09 Hour	IBRD (2013)
MDQ Population in 2019	2,766,240	Alvear et al. (2016)
Average Annual Travel Times Spent on Congestion	31 Hours	INRIX (2017)
Anticipated Congestion Reduction Rate of LRT	2 Percent	IBRD (2013)/Half of Metro
Anticipated Annual Carbon Emissions Reduction	67,000 Metric Tons	IBRD (2013)
Capital Costs	$538,421,067	IBRD (2013)/40% of Metro
Train Set Costs	$82,404,018	IBRD (2013)/40% of Metro
Operating Costs in 2019	$25,641,744	IBRD (2013)/40% of Metro
Annual Station Services Costs per Station	$182,159.55	Quddus, Harris, & Graham (2007)/Lower Value
Number of Stations	15	IBRD (2013)

Figure 18: Option II BCA Result

Categories	Value	Percentage
VTTS from Bus Travel	$543 Million	34.8 Percent
VTTS from Other Motorized Travel	$42 Million	2.7 Percent
VTTS through Reduced Congestion	$106 Million	6.8 Percent
Reduced VOC for Public Transport	$8 Million	0.5 Percent
Reduced VOC for Private Surface Vehicles	$848 Million	54.4 Percent
Environmental Benefits	$13 Million	0.8 Percent
Total PV Benefits	**$1,560 Million**	**100 Percent**
Capital Costs	-$538 Million	51.7 Percent
Train Set Costs	-$82 Million	7.9 Percent
Operating Costs	-$380 Million	36.5 Percent
Station Services Costs	-$41 Million	3.9 Percent
Total PV Costs	**-$1,041 Million**	**100 Percent**
NPV Benefits	**$519 Million**	**N/A**

The NPV benefits were $519 million, economically justifying the alternative. As was the case for the first option, its transport benefits were much bigger than its environmental benefits.

Equity

Affordability

Quito's LRT is likely to have a fare of $0.25, given that the new LRT system in Cuenca has set its fare at $0.25 to match the BRT fares (Cuenca High Life, 2012). Applying this value to the hypothetical average commuter spending analysis I conducted earlier for the PLMQ, an average LRT commuter's monthly spending would be $15. This would effectively cap the average monthly transport expenses at 2.8 percent of average monthly net salary after tax and at 2.6 percent of average monthly personal cost of living. Building the LRT system thus has greater affordability than continuing with the PLMQ.

Accessibility

Implementing the LRT system would have implications for accessibility similar to those of Option I. It would certainly improve transport accessibility in the urban center, as evidenced by the projected transport benefits. But similarly to the metro, the LRT would fail to increase the accessibility of the population in the neighboring suburban areas.

Hence, with high affordability, high urban accessibility, and low suburban accessibility, the option to implement the LRT system would have overall moderate equity.

Feasibility

Feasibility of Implementation

Feasibility of implementation-wise, LRT lags behind the PLMQ in that LRT requires ground space that is not available on the CHQ corridor. Therefore, if the MDMQ were to proceed with the LRT system's implementation, it would have to construct elevated railways that could possibly raise significant opposition. These elevated railways are likely to not only present challenges regarding construction but also create disharmony between them and the historic layout, landscape, and buildings of the corridor.

In addition, elevated railways are much more vulnerable to earthquake activities. During the Kobe Earthquake of 1995 in Japan, for example, the elevated structure of the Hanshin expressway collapsed entirely, inflicting serious damage (see Figure 19).

Figure 19: Collapse of the Hanshin Expressway

Source: U.S. Department of Transportation Federal Highway Administration, 1996.

To withstand such degree of impact, the MDMQ may enforce more stringent seismic requirements for elevated railways, specifically the concrete piers. The new concrete piers that were built following the Kobe Earthquake were designed to be more structurally resilient as shown in Figure 20. They are three meters wider than the old piers and have a separate 12.5-centimeter spacing through the entire height to distribute the seismic energy across the whole structure. This has an effect of stopping the force from putting pressure on one particular part of the pier (Ghasemi, Otsuka, Cooper, & Nakajima, 1996).

Figure 20: New Piers Adopted After the Kobe Earthquake

Source: Federal Highway Administration, 1996.

Yet, using wider piers to build Quito's elevated LRT system would again be extremely challenging for the very reason that the valley and the CHQ corridor are too narrow for such hefty structures. Since the MDMQ has key interests in preserving the CHQ as much as possible without causing any structural distortions, it is highly likely that the MDMQ would prefer to proceed with the underground PLMQ than the LRT system.

Feasibility of Administration

The ease of administrating the LRT system would be similar to that of operating the metro because of their shared nature as rail-based urban transport. Handling the LRT system might even be slightly easier than managing the metro due to lower costs of operations and less passengers. Overall, the feasibility of administration would be high.

Option III: Expand the Bus Rapid Transit (BRT) System to the Suburban Areas

Benefit-Cost Analysis

The BCA for this policy alternative relied on the following alternative-specific rates and values (see Figure 21).

There are some significant clarifications to make regarding the information listed in Figure 21, however. With regards to the number of total daily suburban BRT trips in 2019, I derived its value by assuming that the CHQ-suburban trips would be one-ninth of the trips made within the urban center (Jarrín Silva, 2014). I first projected the daily urban center BRT trips in 2019 based on 828,000 daily BRT trips in 2013 (IBRD, 2013) using the population growth rate. Then I divided the projected number by nine and got the estimate of 101,792 daily trips.

Average travel times saved for average trip by bus or other motorized vehicles were derived using the data from the Transportation Research Board (TRB). According to the TRB (2003), BRT buses tend to be on average approximately 15 kilometers per hour faster than non-BRT buses. Factoring this in, I calculated that the average travel times saved for average bus trip and private motorized vehicle trip would be 0.271 hour and 0.05 hour respectively.

For anticipated annual carbon emissions reduction, I assumed a proportional relationship between transport mode capacity and carbon-cutting effects. The TRB (2003) suggested that Metrobus-Q has a transport capacity of 8,000 pphpd, which is about one-third of the PLMQ's 23,000 pphpd. Because of this reason and that each new suburban BRT route's length is similar to that of the PLMQ, I calculated that each new BRT route's annual carbon reduction would be around 20,100 metric tons. As there would be four new routes, I concluded that the total amount of carbon that this alternative could reduce would be 80,400 metric tons annually. This is consistent with the UN-Habitat (2013)'s report that in a given trip distance, rail-based transport generally has greater carbon-reducing capacity than road-based transport.

With respect to capital costs per kilometer, I tried to obtain information about the existing Metrobus-Q network's capital costs. The best available data was on the construction of the Trolebús corridor in 1995, and it listed $5 million as capital costs per kilometer (TRB, 2003). I CPI-adjusted this value to 2018 dollars, which resulted in $8,063,180.

Figure 21: Specific Rates and Values for Option III BCA

Rate and Value Name	Numerical Value	Source/Justification
Total Daily Suburban BRT Trips in Quito in 2019	101,792 Trips	IBRD (2013)/11% of Urban Center BRT
Average Travel Times Saved for Average Bus Trip	0.271 Hour	Used Data from IBRD (2013) and TRB (2003)
Average Travel Times Saved for Average Trip by Other Motorized Vehicles	0.05 Hour	Used Data from IBRD (2013) and TRB (2003)
Anticipated Annual Carbon Emissions Reduction	80,400 Metric Tons	IBRD (2013)/30% of Metro/LRT Carbon Reduction Capacity and Having Four Routes
Capital Costs per Kilometer	$8,063,180	TRB (2003)
Total Length per New Route	20 Kilometers	Google Map Estimates
Number of Routes	4	Jarrín Silva (2014)

Figure 22: Option III BCA Result

Categories	Value	Percentage
VTTS from Bus Travel	$314 Million	33.6 Percent
VTTS from Other Motorized Travel	$16 Million	1.7 Percent
Reduced VOC for Public Transport	$6 Million	0.6 Percent
Reduced VOC for Private Surface Vehicles	$585 Million	62.5 Percent
Environmental Benefits	$15 Million	1.6 Percent
Total PV Benefits	**$936 Million**	**100 Percent**
Capital Costs	-$645 Million	100 Percent
Total PV Costs	**-$645 Million**	**100 Percent**
NPV Benefits	**$291 Million**	**N/A**

The BCA economically justifies the alternative with NPV benefits being $291 million. The share of environmental benefits out of total benefits for this option is greater than those of the previous two. But environmental benefits are still negligible compared to transport benefits.

Equity

Affordability

This alternative to expand the BRT network to the suburbs would score the same as the option to implement the LRT system in terms of affordability. Metrobus-Q's fares have stayed at $0.25 for years now, and they are unlikely to increase in the near future.

Accessibility

The clear edge that the option to expand the BRT system to suburban areas has over the other two options is that it addresses the accessibility issues of the population living away from the city center. More than 133,000 public transport trips and 85,000 private transport trips were made from the surrounding suburbs of Pomasqui, Calderón, Tumbaco, and Valle de Los Chillos to the CHQ in 2009 alone (Jarrín Silva, 2014). The BRT expansion to these areas would greatly reduce these trips' duration. It would also induce new travels that the inadequate supply of fast and reliable public transport would otherwise curtail.

By routing these new BRT lines carefully, this option may also positively influence urban residents and provide them with heightened transport accessibility. Yet, there is also a risk that poor routing may increase traffic congestion for urban residents, being equitable only to the suburban residents.

Feasibility

Feasibility of Implementation

The Metrobus-Q network has performed successfully over the last two decades and there would be considerable political support from the majority of residents and elected officials for the network's expansion.

But aside from this, the plan to replace some of the existing suburban bus lines with the BRT system could run into severe opposition from interest groups, namely the current non-BRT transit operators. Hidalgo and Graftieaux (2007) stated that when the Trolebús corridor was opened for the first time in 1995, the opposition protested so fiercely that the city had to suffer from major disruptions. Even the army had to be brought in to respond to the situation. Hidalgo and Graftieaux also described that this ended with the creation of a new process in which all historic operators are automatically involved in direct negotiations. This has led to the development of an unbalanced relationship between the government and existing operators, the latter being able to assert conditions and contracts that increase inefficiencies.

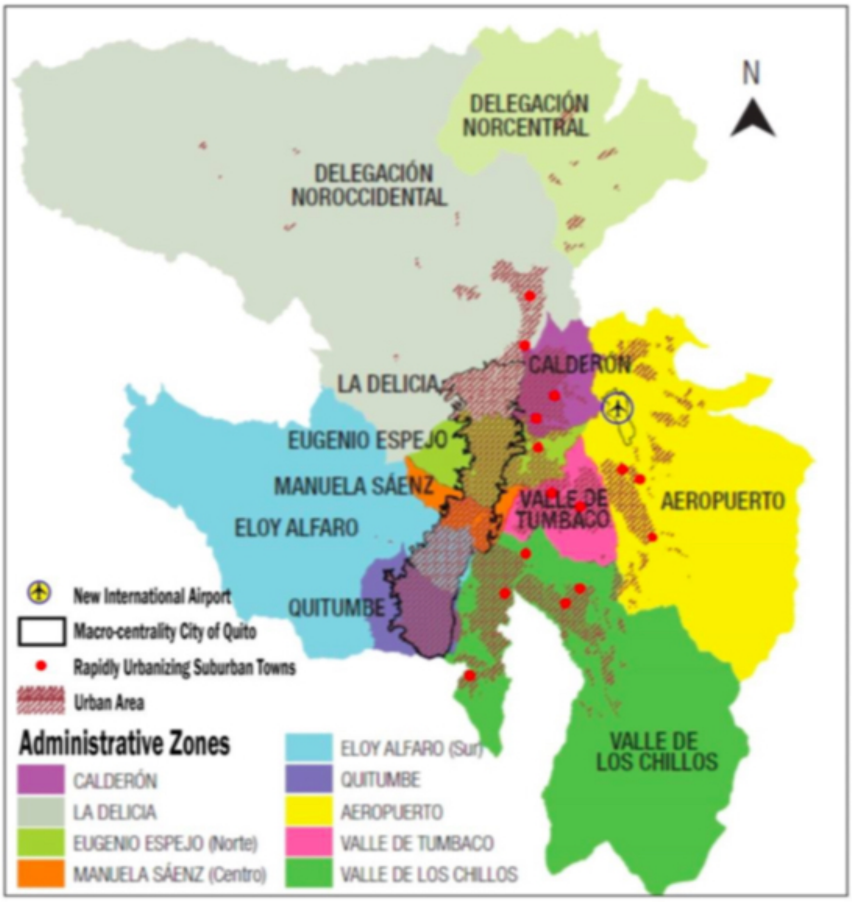
Flores-Dewey and Zegras (2012) also noted that attempting to maximize the inclusion of existing bus operators to the new BRT system could produce undesirable outcomes such as low performance, diminished governmental leverage to regulate the new system, increased operating costs, and inability to expand or integrate the system in the future.

These points suggest that it would be difficult to overcome the expected and likely opposition from existing operators. They also indicate that overcoming this opposition is very likely to compromise some of the key factors associated with the new BRT system including efficiency and regulatory leverage. For these reasons, the feasibility of implementation is going to be moderate overall.

Feasibility of Administration

At the same time, the BRT expansion plan could face administrative difficulties because the extended network would pass through different administrative zones with different governing authorities. As shown in Figure 23, the MDQ is divided into 11 administrative zones, which are further divided into 65 parishes (Jarrín Silva, 2014). Though the MDMQ exercises central authority and the BRT network itself would be operated by the Metropolitan Transport Services and Administration Company (EMSAT), the Metrobus-Q equivalent of the EPMMQ, administrative zones might still prevent the management of the new lines from being seamless. It is possible that each administrative zone would try to relegate network-relevant issues and problems to one another while trying to gain as much as possible from the network.

Figure 23: Administrative Zones of the MDQ



Source: Adapted from Jarrín Silva, 2014.

Another coordination issue may occur when the new BRT lines all converge around the CHQ corridor and add more problems to the chronic traffic congestion issue in the area. Quito's geographic constraints of being on a narrowly stretched valley that is at most three miles wide does not leave out much space for urban planners to be flexible with. Therefore, some degree of traffic convergence at one focal point of area would be nearly unavoidable, rendering administration against congestion quite challenging.

Because of these set of reasons, this alternative has overall low feasibility of administration.

CONCLUSION

Recommendation

Based on the outcomes matrix and analysis, I recommend Option I to let present trends continue and keep the PLMQ. Comparing it with Option II, although its NPV benefits are smaller, Option I's transport benefits are as twice as big as the second option's. Furthermore, the underground metro has much less likelihood of disturbing the CHQ's layout and existing traffic than the LRT system. It would also be more resilient to earthquakes than Quito LRT's inevitable elevated structures. These points suggest that the PLMQ would meet the needs of the MDQ better than the LRT system.

Comparing it with Option III, both of Option I's NPV benefits and transport benefits are much greater than those of Option III. Though it has less suburban accessibility than the alternative to expand the BRT system to the suburbs, the PLMQ has much greater feasibility of implementation and administration. Given these prospects and the fact that much of the construction and tunneling works are nearing their completion, I would advise the MDMQ and the World Bank to let present trends continue with the PLMQ.

The PLMQ's limits of low suburban accessibility should not be brushed aside, however. After the PLMQ is fully implemented, if budgetary, political, and administrative circumstances allow, the MDMQ and the World Bank may consider implementing the BRT expansion plan. The suburban BRT system could complement the metro's weakness, making the PLMQ a more complete policy solution to the MDQ's traffic and environmental problems.

Implementation

A successful implementation of the PLMQ would depend largely on the process's transparency and accountability. The main criticism and opposition against the PLMQ other than opportunity costs and rapid gentrification is the relative lack of these two features in its execution. This especially became apparent in the recent Odebrecht corruption scandal, which revealed that multiple MDMQ officials had received bribes from the Brazilian construction conglomerate Odebrecht in exchange for favorable contracts. The scandal not only seriously hurt public confidence in the project but also caused significant confusion and delays with Odebrecht being forced to leave the consortium (Gracia, 2017).

To counter these problems, the MDMQ needs to take a more proactive approach in making information available to the public and thereby reducing the difficulty of tracking the current progress of the project. The MDMQ could also establish an impartial transparency and accountability unit detached from its organization to conduct stricter audits and inspections concerning the PLMQ and EPMMQ. The World Bank also needs to continue to enforce certain oversight over the project and the usage of its funds by the authorities and contractors.

Meanwhile, as Salar Khan (2016) argued, the MDMQ and the World Bank should put greater efforts in mitigating the PLMQ's possible negative impacts on the city's environment and historic heritage.

The MDMQ should also develop a more long-term financing scheme to ensure the proper management and maintenance of the huge metro infrastructure (Salar Khan, 2016). EMSAT's reliance on sizeable government subsidies for low fares has raised questions about Metrobus-Q's long-term sustainability (Hidalgo & Graftieaux, 2007). Learning from this case, it would be worth exploring ways in which the EPMMQ could avoid its overdependence on government subsidies while keeping the fare at $0.45 at the same time.

Lastly, if there are enough resources, the MDMQ should work closely with the EPMMQ to equip the PLMQ with ITS capabilities. This could increase system efficiency and thereby positively influence passenger experience and satisfaction.

SENSITIVITY ANALYSIS APPENDIX

Appendix 1: Varying Discount Rates

Discount Rate	Option I: Let Present Trends Continue and Keep the PLMQ	Option II: Implement the Light Rail Transit (LRT) System	Option III: Expand the Bus Rapid Transit (BRT) System to the Suburban Areas
5 Percent	**$500 Million NPV**	**$519 Million NPV**	**$291 Million NPV**
3 Percent	$944 Million NPV	$765 Million NPV	$494 Million NPV
7 Percent	$163 Million NPV	$332 Million NPV	$138 Million NPV
12 Percent	-$383 Million NPV	$28 Million NPV	-$112 Million NPV

Appendix 2: Varying Annual Trip and Population Increase Rates

Trip and Population Increase Rate	Option I	Option II	Option III
1.7 Percent	**$500 Million NPV**	**$519 Million NPV**	**$291 Million NPV**
0.5 Percent	$299 Million NPV	$408 Million NPV	$202 Million NPV
1 Percent	$379 Million NPV	$452 Million NPV	$238 Million NPV
2.5 Percent	$650 Million NPV	$602 Million NPV	$359 Million NPV

Appendix 3: Varying Social Cost of Carbon (SCC)

Social Cost of Carbon (SCC)	Option I	Option II	Option III
$14.69 (5% Average Discount Rate)	**$500 Million NPV**	**$519 Million NPV**	**$291 Million NPV**
$51.78 (3% Average Discount Rate)	$531 Million NPV	$551 Million NPV	$330 Million NPV
$76.44 (2.5% Average Discount Rate)	$553 Million NPV	$572 Million NPV	$355 Million NPV
$151.64 (High Impact)	$617 Million NPV	$637 Million NPV	$433 Million NPV

Note: Each SCC, originally in 2007 dollars, were CPI-adjusted to 2018-value.

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