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SUMMARY SHEET

As environmental problems like climate change continued to thrive over the past decades, more considerations on potential policies have been raised in response. Specifically, the use of renewable energy in public bus transit systems has been a topic of interesting significance. In this problem, our group is tasked to establish a model that replaces current bus systems in metropolitan areas with all-electric bus fleets and evaluate both the ecological and financial measures of our implementation model.

An analysis of the ecological consequences of electric buses is acquired to serve as a basis for our implementation model. We incorporated the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Entropy Weight Method to compare the impacts of e-buses with other types of buses. Specifically, we evaluated four different types of buses, which are **traditional diesel buses**, **biodiesel buses**, **biogas buses**, and **electric buses**, by considering their performance in the four main criteria of noise pollution, greenhouse gases, pollutants, and energy consumption. For the actual modeling and calculation process we narrowed this model down to the consideration of four specific ecological indexes - **CO_2 emission of operation**, **CO_2 emission of production**, **noise pollution**, and **energy consumption** - in the specific case of the SL *(Storstockholms Lokaltrafik)* bus system based in Stockholm, Sweden. At the end of the day, the TOPSIS model indicated that electric buses are the type of bus that could be the most beneficial ecologically.

With that statement found, we considered the implementation policy through a Zero-one Integer Programming model. Since the primary goal of this change is to bring as many ecological benefits as possible under limited funding, the goal of this model would thus be to **maximize the distance covered by electric bus lines** and at the same time **minimize the cost of our implementation process**. Similarly, this model is also carried out in the case of Stockholm, Sweden. To approach the final optimization, we would narrow down the possible lines for replacement, organize an optimized plan for the locations of charging sites, and ensure that this process could be performed under the budget constraint of 50% of the total investment needed that will be injected into our project in the form of external government funding. However, to optimize this policy and make it more realistic, we incorporated a 10-year timeframe and the consideration of **generative income** that will allow profit earned by the bus system itself to sustainably maintain the cost of our implementation process. After establishing a realistic simulation of a replacement process in Stockholm, Sweden, we would apply this model further to other metropolitans like Chicago, USA, and Shanghai, China.

At the end of the day, our model will support us in carrying out a detailed plan of a proposal that incorporates specific data on the bus lines replaced, the places where charging infrastructures should be implemented, and the distance covered by the implementation over our 10-year timeframe,to show a realistic simulation of how transportation officials in metropolitan areas could take their steps to help all of us envision a better ecological environment.

Keywords - Optimization, TOPSIS, Entropy Weight Method, Zero-one Integer Programming Models, Temporal Planning, Stockholm, Chicago, Shanghai

CONTENTS

I. INTRODUCTION

1. Background

In recent decades, problems relating to climate change, such as global warming, have worsened, raising the public's awareness and concerns on related issues. In the European Union, policies providing tax incentives for electric vehicles have been implemented since 2010 [1], replacing traditional types of vehicles with eco-friendly vehicles. As a country in the European Union, Sweden actively promotes the energy transition. By September 2018, all public transport in its capital, Stockholm, already operates with 100% fossil-free fuel. Compared to traditional diesel vehicles, the alternative, Biodiesel vehicles, is not only a fully renewable alternative but can also reduce CO_2 emissions by up to 90% [2].

However, due to increased population growth and urbanization, the demand for public transportation is constantly rising. The optimization presented by current policies might need to be improved. Taking Stockholm's bus service as an example, the community's long-term benefit might necessitate further changes.

One potential change will be replacing the city's current bus system, mainly comprising of biodiesel and biogas buses, with electric buses. Such actions can benefit the citizens through various ecological aspects such as sound and air pollution decreases. Data also demonstrates a significant decrease in the price of electronic vehicle batteries in the last decade[3]. Therefore, in the long term, it could bring welfare to citizen's everyday life and the country's overall GDP. But drawbacks to such policies are apparent: the change requires lots of resources, is very expensive, could be limited by various elements, etc. Considering the pros and cons of such modifications, a plan that considers all aspects strategically and comprehensively must be provided before incorporating e-bus services in the city.

2. Problem Restatement

Our model focuses mainly on the ecological and economic concerns of replacing current buses in Stockholm with e-buses. Analyzing the ecological and economic impacts of this bus-type conversion is our primary objective. Then, we will provide a 10-year roadmap for transport authorities to plan their e-bus fleet updates. Therefore, our paper will contain these of the following:

First, we need to construct an evaluation model that shows the ecological consequences of running an all-electric bus fleet in a metropolitan area.

Second, we need to construct a financial model that analyzes the financial implications of conversing to e-buses if we have an external fund covering 50% of the total cost. The economic model will indicate different financial strategies that we will adopt to balance out the costs with the e-bus fleet's profit.

Third, we need to craft a 10-year blueprint for conversing all combustion engine buses to electric ones by 2033 for the metropolitan area we selected. Meanwhile, we should apply our models to two additional metropolitan areas. Combining the results of the two previous models, we should demonstrate how this can be achieved through policy management and cost control.

Finally, we summarize and present our results in a one-page letter to the transportation officials of the metropolitan area we choose, through which we will demonstrate the feasibility of our 10-year plan and the cost management for the bus-type conversion.

3. Literature Review

The replacement of the traditional public transportation system with a new eco-friendly public transportation system received extensive attention from the masses. Much research has already been conducted on this subject. Here, we provide a review of various articles that studied a similar topic.

- *"Locating charging infrastructure for electric buses in Stockholm" by Maria Xylia et al.*
  Within the article, a model is constructed and applied to optimize the distribution of charging infrastructure for electric buses within Stockholm. The model demonstrates that the highest concentrating locations for installing charging infrastructure are around major public bus transport hubs that are connected to other public transport systems. The cost of installation is within a reasonable range while reducing emissions and energy consumption. The model could be also applied to other urban contexts.

- *"Distributional effects of public transport subsidies" by Maria Börjessona et al.*
  The authors of the article analyze the distribution of transit subsidies among citizens in Stockholm. Using a method, they calculated the subsidy per trip in the transit network and the distribution of the subsidies. The subsidy rate varies from 0 percent to 67 percent across the country and almost every income group has approximately the same average subsidy per person. Thus, the authors conclude that transit subsidies are ineffective as a redistribution policy in Stockholm.

4. *Our Work & Model Overview*

Our model is designed to simulate an implementation replacing current bus systems with all-electric bus fleets. It would first incorporate **the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Entropy Weight Method** to evaluate the ecological consequences of electric buses compared to other types of buses in current public transit systems. Then, we would acquire **zero-one integer programming method** to simulate the actual implementation process and plan out a 10-year roadmap as a proposed replacement solution with an all-electric bus fleet under realistic financial considerations.

II. ASSUMPTIONS AND JUSTIFICATIONS

Assumption 1. The implementation of electric buses would not notably influence the number of people traveling by bus.

Justification 1. Whether the bus system is comprised of current types of buses (traditional diesel bus, biodiesel bus, biogas bus, etc.) or electric buses should not be a significant factor influencing a person's choice to take a bus. In other words, this policy would not affect people's choice to take a bus.

Assumption 2. Governmental profit is gathered from the bus system should be fully used in furthering the e-bus replacement project until all bus lines are e-bus lines.

Justification 2. To approach a massive project of change in a critical social system with limited external funding, city officials should have the incentives to use the profit generated by the bus system for implementation. With only 50% of needed funding at most, implementing our plan would require more money from this system to fulfill our ultimate goal; thus, we exclude the possibility that governments may want to use these monetary profits in other sectors of the economy.

Assumption 3. Extensions of our models would not adjust for all the minimal differences between different cities.

Justification 3. Since our model is designed for a more general situation (based on Stockholm, Sweden, to some extent), this model is not perfectly appropriate for the actual situation of all cities. This means that to maintain a sense of flexibility in generalizing our model to more places, we forbid this model from entirely binding with a single city or a single place, so adjustments for some of the unique features of certain cities are not required.

Assumption 4. The features of electric buses are identical to traditional buses that are prevalent in current bus systems except for the main features that define their differences, including how they are fueled.

Justification 4. This paper and the constructed models aim to determine the ecological consequences of a potential implementation of e-bus systems and how they could function in particular cities in our world.

This means that excluding the impacts of other distinctions between the different types of buses in factors like capacity, speed, or efficiency would allow us to focus on the more important interests of this paper.

Assumption 5. There are no major technological developments, shifts in perception on the significance of environmental sustainability, or other massive events that could seriously impact the implementation of electric buses.

Justification 5. In the status quo, the world is growing rapidly; it is also reasonable to claim that this world is not in a particularly stable order. However, we would have to assume the absence of significant incidents that could significantly change our world for this modeling to be feasible. With this assumption, our current statements will be meaningful.

III. NOTATIONS

Table 3-1: Symbols and Units of Used Parameters (Partial)

Parameter	Symbol	Units
Coverage distance	$d_{T,\text{e-bus}}$	km
Maximum Capacity	$E_{\max}$	kWh
Energy Consumption Rate	r_{consume}	kWh/km
Government Funding	G_F	SEK/USD/CNY
Time Between Each Departure	t_{depart}	h
Speed of E-bus	v	km/h

The notations provided in Table 3-1 are only a section of our used parameters. A more detailed and complete set of parameters with their symbol and unit is provided in Table 5-1, Table 6-1, and Table 6-2.

IV. THE ECOLOGICAL CONSEQUENCES OF E-BUS IMPLEMENTATION

1. Problem Objective

This problem aims to assess the ecological consequences of transitioning to an exclusively electric bus fleet within the urban public transportation network.

To address this problem, we construct a model contrasting the ecological consequences of running a network of four bus types (biogas-fueled, biodiesel-fueled, or electric buses) in **Stockholm**. To be specific, we employ **the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)** to scrutinize the performance of each bus type across various evaluation criteria, including *the carbon dioxide (CO_2) emissions during production, Average Decibel Levels, and so on*. Meanwhile, we utilize the **Entropy Weight Method** to assign weights to each evaluation criterion, thereby capturing their relative significance in the overall assessment. The flowchart of our method is shown in Figure 4-1.

The core of our analysis lies in the TOPSIS model, which facilitates the computation of the ecological implications associated with each bus type. This evaluation allows for a nuanced understanding of elucidating the differential contributions of different bus types to the ecological footprint of the public transportation system. Hence, by building a model to analyze this problem, we contribute to the broader discourse on sustainable urban mobility and offer insights that can inform evidence-based decision-making in pursuing environmentally responsible public transportation solutions.

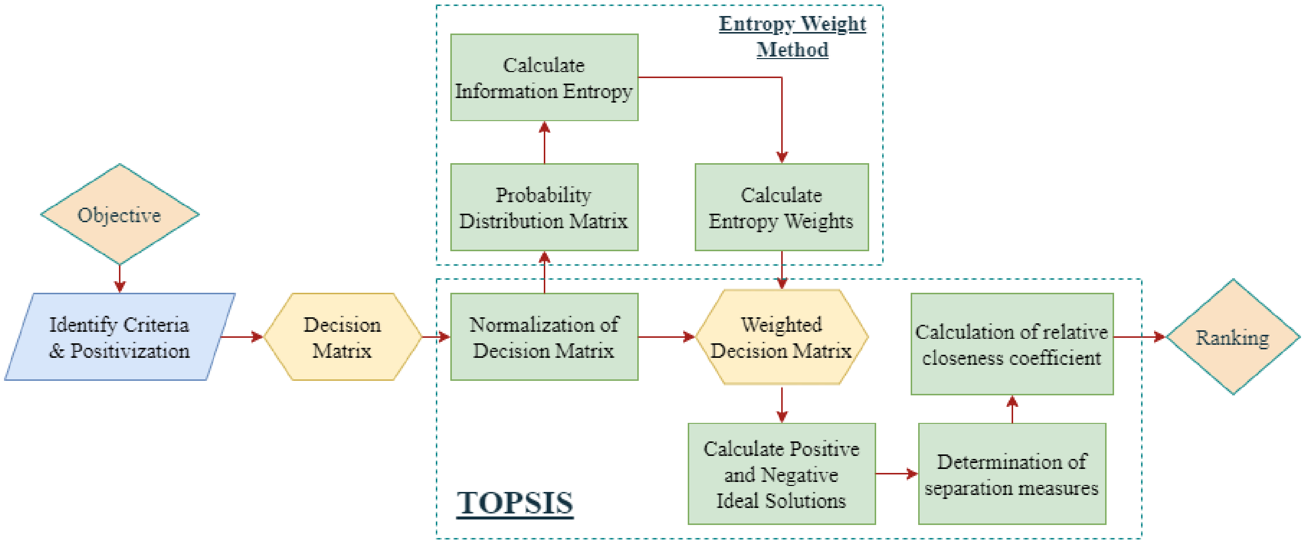

Figure 4-1: EWM+TOPSIS Evaluation Model

2. *Ecological Consequences Analysis based on EWM-TOPSIS Evaluation Model*

a. *Establishment of Evaluation Metric System:*

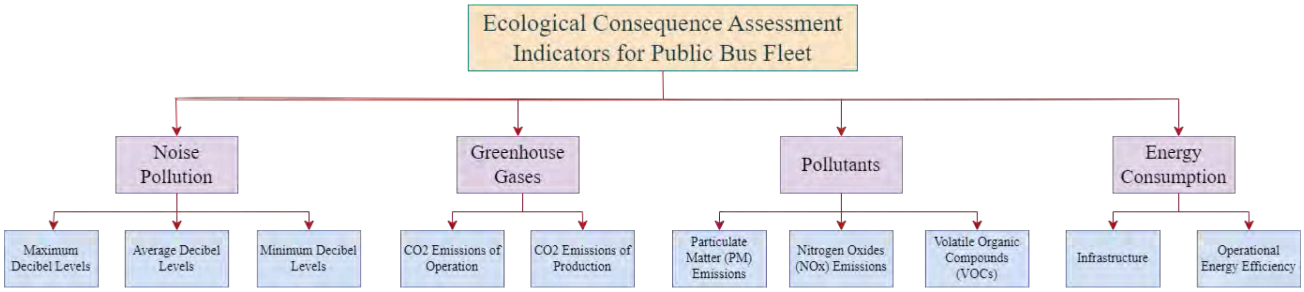

Figure 4-2: Evaluation Metric System

1. *Noise Pollution*

Maximum Decibel Levels. Maximum decibel levels refer to the highest noise intensity emitted by buses. Excessively high decibel levels can contribute to noise-related health issues and disturbance of urban soundscapes.

Average Decibel Levels. Average decibel levels measure the overall noise pollution generated by buses. This aids in understanding the day-to-day auditory experience of individuals in proximity to public transit routes.

Minimum Decibel Levels. Minimum decibel levels represent the lowest observed noise emissions during idle or low-activity periods. This metric is valuable for understanding the baseline noise level when buses are inactive.

2. *Greenhouse Gases*

CO_2 Emissions of Operation. This metric encompasses the combustion-related emissions during regular service, providing insights into the contribution of each bus type to atmospheric CO_2 levels.

CO_2 Emissions of Production. CO_2 emissions in bus production are the CO_2 released during the manufacturing process, encompassing raw material extraction, manufacturing, and assembly.

3. *Pollutants*

Particulate Matter (PM) Emissions. Particulate matter emissions gauge the release of micro-particles. It has potential health implications of PM exposure, making it crucial for assessing the buses' contribution to air quality and public well-being.

Nitrogen Oxide (NOx) Emissions. NOx is a precursor to air pollution and has environmental and health consequences. They are pivotal for evaluating the buses' impact on air quality.

Volatile Organic Compounds (VOCs). VOCs contribute to air pollution, which leads to diverse environmental effects. It ensures a more comprehensive evaluation of the buses' emissions profile.

4. *Energy Consumption*

Infrastructure. Infrastructure-related energy consumption measures the energy requirements for establishing bus facilities, such as charging stations. It evaluates the broader energy implications associated with the transition of bus types.

Operational Energy Efficiency. Operational energy efficiency evaluates the energy consumption efficiency of buses during regular service. This metric is essential for understanding the practical viability of each bus type in terms of energy utilization.

b. *Positivization and Normalization of Decision Matrix:*

In the TOPSIS methodology, the first step involves positivizating and normalizing the raw data to eliminate scale-related biases.

Table 4-1: Ecological Indexes of Different Bus Types

Bus Type	CO_2 Emission in Operation (gCO_2/km)	CO_2 Emission in Production ($kgCO_2$/GGE of Energy)	...	Energy Consumption (kWh/km)	Noise Pollution (dBA)
Diesel Buses	1151.4[4]	8.88[5]	...	4.13[6]	68[7]
Biodiesel Buses	12.76[8]	3.40[9]	...	4.50[8]	68[10]
Biogas Buses	13.55[8]	2.53[11]	...	6[8]	70[7]
Electric Buses	0[8]	3.32[12]	...	1.50[8]	63[7]

Based on the raw data above, the decision matrix, denoted as $X(t)$ of type t, is generated; where n denotes the number of criteria, and m denotes the four different bus types.

$$X(t) = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix}$$

Next, it is necessary to carry out the positivization process of the data. The inconsistent dimensions of the criteria can lead to variations in data magnitudes, which can potentially influence the calculation results.

In this problem, we categorize our criteria into benefit and cost criteria. Benefit criteria represent criteria where higher values are favorable, while cost criteria involve criteria where lower values are desirable. Within the scope of our evaluation criteria, criteria such as CO_2 Emissions are classified as cost criteria. Criteria such as Minimum Decibel Levels are identified as benefit criteria.

For benefit criteria, no positivation is needed. $\tilde{x}_{m1} = x_{m1}$.

For cost criteria, $\tilde{x}_{ij} = \max\{x_{ij}\} - x_{ij}, i \in [1..n]$.

Then, to render the set of criteria compatible for meaningful comparison, we employ the **Vector Normalization technique** as a pivotal step in the normalization process. We transform the $X(t)$ matrix to $Z(t)$, denoting each normalized criterion as z_{ij}.

$$z_{\mathrm{ij}} = \frac{\tilde{x}_{\mathrm{ij}}}{\sqrt{\sum_{i=1}^{m} \left(\tilde{x}_{\mathrm{ij}}\right)^2}}, i \in [1..\mathrm{n}], j \in [1,\mathrm{m}]$$

Ultimately, the normalized decision matrix should be:

$$Z(t) = \begin{pmatrix} 0.494797 & 0.000131 & ... & 0.144914 \\ 0.494797 & 0.988919 & ... & 0.672669 \\ 0.479938 & 0.988233 & \cdots & 0.755906 \\ 0.531944 & 1.000000 & ... & 0.680469 \end{pmatrix}$$

c. *Entropy Weight Method for Weight Calculation:*

To determine the weights of the criteria, we employed the Entropy Weight Method (EWM) as a pivotal step in our analytical model. EWM is an objective weighting technique that employs information entropy calculations to compute the entropy weights for each criterion. In comparison to subjective methodologies like the Analytic Hierarchy Process (AHP), EWM can objectively determine the significance of each criterion by considering the information entropy inherent in the data.

The entropy weight w_j for each criterion is calculated through the following steps:

Firstly, we need to construct a Probability Distribution Matrix $P(t)$ based on the previous normalized matrix $Z(t)$, where p_{ij} represents the normalized score of the bus type i for criterion j.

Next, we need to calculate the Information Entropy e_j, where e_j denotes the entropy value for criterion j:

$$e_j = -\sum_{i=1}^{m} p_{\mathrm{ij}} \frac{\ln\left(p_{\mathrm{ij}}\right)}{\ln(m)}$$

Then, we need to calculate the Coefficient of Variation:

$$g_j = 1 - e_j$$

Hence, we are able to obtain w_j:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

In this case, the weights of our criteria are obtained, which reflect the relative importance of each criterion in contributing to the overall evaluation.

d. *TOPSIS Evaluation Model:*

Having established the weighted criteria through the Entropy Weight Method (EWM), we proceed to employ TOPSIS model. This method facilitates a comprehensive ranking of alternative solutions(referring to different bus types in this context) based on their proximity to the ideal solution while considering both positive and negative criteria.

Firstly, we need to calculate the Weighted Normalized Decision Matrix $W(t)$. $W(t)$ is computed by element-wise multiplication of the normalized decision matrix $Z(t)$ with corresponding weights w_j.

$$W(t) = W_j \cdot Z(t)$$

Then, according to TOPSIS, the ideal and anti-ideal solutions should be determined. We denote W_j^+ as the maximum value in the jth column of $W(t)$, which is the ideal solution; and we denote W_j^- as the minimum value in the jth column of $W(t)$, which is the anti-ideal solution.

$$W_j^+ = (W_1^+, W_2^+, ..., W_m^+) = (\max\{w_{11}, w_{21}, ..., w_{\mathrm{m1}}\}, ..., \max\{w_{\mathrm{1n}}, ..., w_{\mathrm{mn}}\})$$

$$W_j^- = (W_1^-, W_2^-, ..., W_m^-) = (\min\{w_{11}, w_{21}, ..., w_{\mathrm{m1}}\}, ..., \min\{w_{\mathrm{1n}}, ..., w_{\mathrm{mn}}\})$$

Next, we need to calculate distance of each bus type from W_j^+ and W_j^-. D_i^+ represents the distance of the ith bus type from the ideal solution, and D_i^- represents the distance of the ith bus type from the anti-ideal solution. The Euclidean distance is used to calculate the distance.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(W_j^+ - W_{\mathrm{ij}}\right)^2}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(W_j^- - W_{\mathrm{ij}}\right)^2}$$

In this case, now we are able to calculate the approximate degree C_i between each bus type and the optimal scheme. The range of C_i is (0,1). The closer it is to 1, the better the evaluation object is. We denote C_i as the TOPSIS score obtained for the ith bus type.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

3. Model Results

Ultimately, after calculating and ranking all the C_i, we obtain the following scores:

Table 4-2: TOPSIS Score of Different Bus Types

Bus Type	Score
Diesel Buses	0.041160
Biogas Buses	0.904752
Biodiesel Buses	0.926741
Electric Buses	0.970086

Diesel Buses: Score - 0.041160. Diesel buses exhibit the lowest TOPSIS score, implying comparatively lower proximity to the ideal solution regarding ecological consequences. This outcome aligns with expectations, as diesel buses are often associated with more serious environmental impacts.

Biogas Buses: Score - 0.904752. Biogas buses demonstrate a relatively high TOPSIS score, indicating a significant proximity to the ideal solution. This outcome suggests that biogas buses perform favorably in terms of the evaluated ecological criteria, potentially owing to their cleaner fuel source and reduced environmental footprint.

Biodiesel Buses: Score - 0.926741. Biodiesel buses exhibit a high TOPSIS score, suggesting a notable proximity to the ideal solution. This result underscores the relatively positive ecological performance of biodiesel buses, potentially attributed to the use of biodiesel fuel.

Electric Buses: Score - 0.970086. Electric buses present the highest TOPSIS score among the evaluated bus types. This outcome underscores their exceptional proximity to the ideal solution in terms of ecological consequences. Electric buses emerge as the most environmentally friendly option in this assessment.

We select four core evaluation criteria to display here so as to contribute to a holistic understanding of their respective environmental impacts.

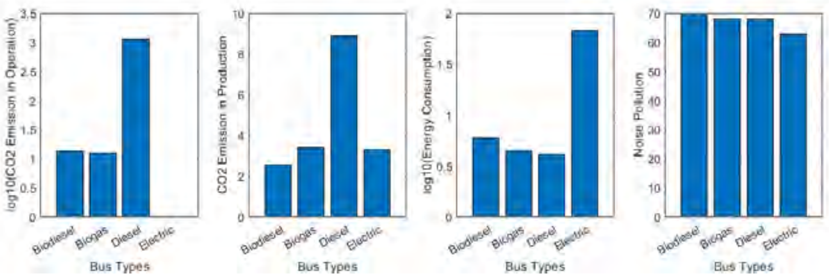

Figure 4-3: Ecological Indexes of Different Bus Types

With electric buses showing the highest score, it would be safe to claim that transitioning from any of the other types of buses to an all-electric bus fleet would be ecologically advantageous.

To further quantify the consequences, we hypothesize four transitions with the magnitude of Stockholm's bus system. Annually, vehicle kilometers in operations of the SL bus lines is 1.23 million kilometers per inhabitant[13]. Applying it to Stockholm's inhabitant population of 985 thousand[14], this means that there will be 122 billion kilometers traveled by the entire bus system annually. With this magnitude, we can now gather the quantifiable changes in a city's environment under a hypothetical transition from an all-diesel bus fleet, an all-biodiesel bus fleet, or an all-biogas bus fleet to an all-electric bus fleet to show how electric buses influence the environment. Calculated results are shown in Table 4-3.

Table 4-3: Change of Ecological Indexes in Transitions

Transition From (Bus Fleet)	Transition To (Bus Fleet)	Decrease in Total CO_2 Emission (*billion tonnes of CO_2*)	Decrease in Energy Consumption (*billion kWh*)	Decrease in Noise Pollution (*dBA*)
All-Diesel	All-Electric	255.82	503	5
All-Biodiesel	All-Electric	39.19	365	5
All-Biogas	All-Electric	38.85	548	7

4. Conclusion

In conclusion, the evaluation of the ecological consequences associated with different bus types through the lens of different criteria has yielded valuable insights into their relative performance. The TOPSIS scores, based on the weights obtained through EWM, reflecting the proximity of each bus type to the ideal solution, provide a nuanced perspective on their environmental impact.

Electric buses emerge as the most environmentally friendly option, garnering the highest TOPSIS score. The commendable performance of electric buses positions them as a promising and sustainable solution for urban public transportation systems.

V. FINANCIAL IMPACT ANALYSIS OF E-BUS IMPLEMENTATION

1. Problem Objective

As we have justified previously, the usage of e-bus in transport systems largely benefits Stockholm ecologically. For the welfare of the citizens in the city, replacing diesel buses with e-buses is one of the primary goals the government attempts to accomplish. Yet this ideal city development is largely hindered by financial difficulties. Purchasing e-buses, along with the installation of charging infrastructures, is extremely costly. To make our project more realistic, our group established a 50% external funding restriction. In other words, the government will only cover up to 50% of the total cost for an entire replacement process.

For the convenience of our calculations, we excluded bus routes that travel beyond the city of Stockholm. We also excluded routes of special buses (e.g. flygbussarna). The model provided afterward will be based on the remaining 253 bus lines and 2324 stations on these bus lines in Stockholm. Data is extracted from the official website of Sweden.

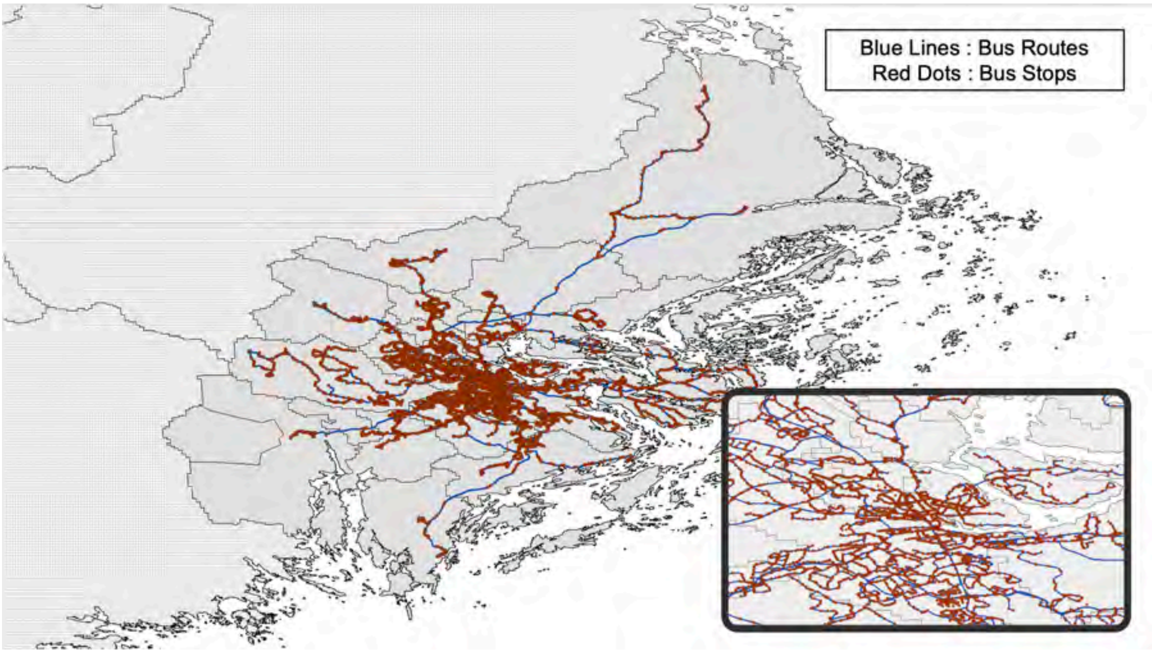

Figure 5-1: Bus Line Map with Bus Stops

Based on that, we provide an optimal plan for using the limited budget efficiently. The plan minimizes the cost of construction and maximizes the area covered by the e-bus routes. To achieve this goal, we constructed three zero-one integer programming models. The first model calculates the minimal number of charging infrastructures required to complete the replacement process. The second model calculates the minimal number of buses required. The third model calculates the maximum distance covered by the e-bus routes given the financial restraints. The process is demonstrated in the following flow chart.

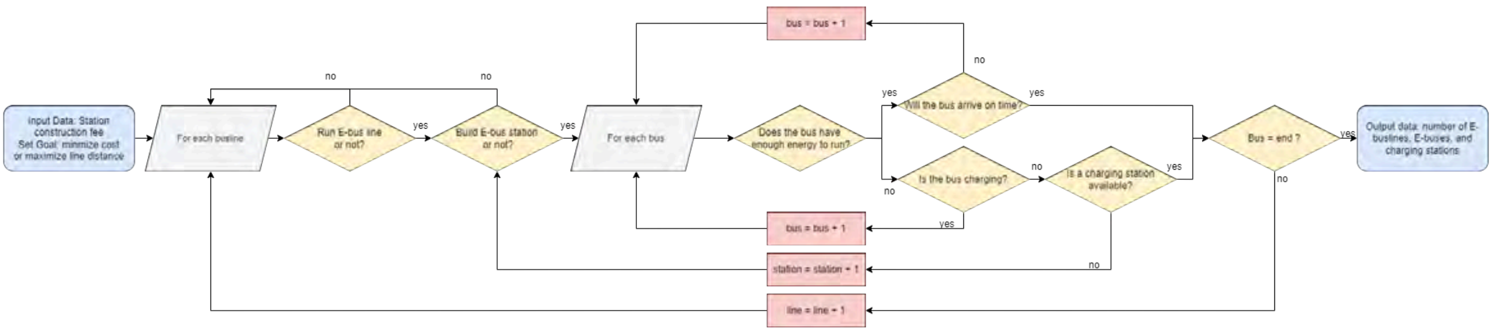

Figure 5-2: Finantial Impact Analysis Model Flow Chart

2. *Model Explanation*

a. *Decision Variables:*

The ultimate objective of our model is to identify which of the bus routes will be translated into e-bus routes given only the initial government funding (50% total cost). Thus, our decision variable is whether a route is converted to an e-bus route or remains the traditional bus route. The expression is shown in Eq. (5-1).

$$\mathrm{TUS}_l \begin{cases} \text{E-bus route} = 1 \\ \text{Fuel-bus route} = 0 \end{cases} \tag{5-1}$$

TUS_l represents the cities' l'th route within the city. 1 means that this route is an e-bus route, and 0 means it is a traditional bus route.

Not all stations need to install a charging infrastructure. Thus, a station can be categorized as either a charging site or a non-charging site. The expression is shown in Eq. (5-2).

$$\mathrm{US}_{\mathrm{l,s}} \begin{cases} \text{E-bus station} = 1 \\ \text{Fuel-bus station} = 0 \end{cases} \tag{5-2}$$

$\mathrm{US}_{\mathrm{l,s}}$ represents the s'th station in the l'th route. 1 means that this station has a charging infrastructure and 0 means this station doesn't. We assume that there is a base close to the starting station of each bus line where e-buses can charge. Infrastructure inside this base is also calculated, although it will not be displayed by the variable.

b. *Objective function:*

To maximize the utility of government funding, we consider two aspects: (i) to minimize the cost of construction and (ii) to maximize the coverage of bus routes. Hence, we identify three objective functions.

The first objective function identifies the total number of charging infrastructures required in the transport system. The expression is shown in Eq. (5-3).

$$N_{\text{infrastructure}} = \sum_{l=1}^{L} \sum_{s=1}^{S} \mathrm{US}_{\mathrm{l,s}} \tag{5-3}$$

$N_{\text{infrastructure}}$ represents the number of charging infrastructures built.

The second objective function identifies the total number of e-buses required in the transport system. The expression is shown in Eq. (5-4).

$$N_{T,\text{e-bus}} = \sum_{l=1}^{L} \mathrm{TUS}_l \cdot N_{l,\text{bus}} \tag{5-4}$$

$N_{T,\text{e-bus}}$ represents the total number of e-bus in Stockholm, $N_{l,\text{bus}}$ represents the number of buses in the l'th bus route.

The third objective function identifies the coverage of e-bus routes. The expression is shown in Eq. (5-5).

$$d_{T,\text{e-bus}} = \sum_{l=1}^{L} \mathrm{TUS}_l \cdot d_l \tag{5-5}$$

$d_{T,\text{e-bus}}$ represents the total distance covered by the e-bus routes, d_l represents the distance covered by the l'th bus route.

c. *Restraints:*

In our model, we consider the complete course traveled by the buses. This means that every bus has to travel to its destination and return to the starting station to be considered as a single journey. We assume that for every bus in a route, the starting station and destination are identical. And since electricity will be consumed within the journey, we have to make sure that the bus will always contain a sufficient amount of electricity to complete the remaining traveling distance to the next charging station. The calculation of energy stored in the battery is shown in Eq. (5-6).

$$\begin{cases} E_{\text{l,s}}^{\text{input}} + E_{\text{charge}} = E_{\text{l,s}}^{\text{output}} \\ E_{\text{l,s}}^{\text{input}} = E_{\text{l,(s-1)}}^{\text{output}} + r_{\text{consume}} \cdot d_l \end{cases} \tag{5-6}$$

$E_{\text{l,s}}^{\text{input}}$ represents the energy stored in the E-bus battery when entering the sth station of the lth bus route. $E_{\text{l,s}}^{\text{output}}$ represents the energy stored in the battery when leaving the sth station of the lth bus route. E_{charge} represents the energy supplied to the battery by the charging infrastructure within the station. r_{consume} represents the energy consumption rate of the e-bus.

During the entire process of traveling, the energy stored in the battery will not exceed the maximum capacity of the battery and must always be above a minimum value to promise safe driving. Thus, Eq. (5-7) must always hold true.

$$\begin{cases} E_{\text{l,s}}^{\text{output}} \leq E_{\max} \\ E_{\text{l,s}}^{\text{input}} \geq E_{\min} \end{cases} \tag{5-7}$$

Furthermore, for every bus line, we must make sure a certain number of buses are put into use. That is, the number of buses in a line should be able to fulfill the schedule for the departure of the buses. Specifically for e-bus lines, after every certain amount of time, an e-bus must be fully charged and ready to depart from the starting station. Eq. (5-8) must always hold true.

$$t_{\text{depart}} - \frac{2d_l}{v} + t_{\text{depart}} \cdot \left(N_{l,\text{bus}} - 1\right) > \frac{2 \cdot r_{\text{consume}} \cdot d_l - \sum_{s=1}^{S} \cdot \text{US}_{l,s} \cdot r_{\text{charge}} \cdot t_{\text{charge}}}{r_{\text{charge}}} \tag{5-8}$$

t_{depart} represents the elapsed time between departures. v represents the average speed of e-buses.

And most importantly, there are the budget restraints. The government funding will not exceed the total expenditures used for the transformation process.

$$F_{\text{Gov}} \geq \sum_{l=1}^{L}\sum_{s=1}^{S}\left(\text{US}_{\text{l,s}} \cdot C_{\text{infrastructure}}\right) + \sum_{l=1}^{L}\left(\text{TUS}_l \cdot N_{l,\text{bus}} \cdot C_{\text{e-bus}}\right) \tag{5-9}$$

F_{Gov} represents the fund provided by the government. $C_{\text{infrastructure}}$ represents the cost of installing a charging infrastructure and C_{bus} represents the cost of purchasing a new e-bus for the system.

d. *Zero-one Integer Programming Models:*

The combination of the decision variables, objective functions, and restraints sets up our zero-one integer programming models. To reduce the financial burden on the investors of this project, which in this case is the government and the public transport company supervising the project, we aim to find the minimum number of buses and charging infrastructures required. Our model is the following:

$$\min N_{\text{infrastructure}} = \sum_{l=1}^{L} \sum_{s=1}^{S} \mathrm{US}_{\mathrm{l,s}}$$

$$s.t. \begin{cases} E_{\mathrm{l,s}}^{\text{input}} + E_{\text{charge}} = E_{\mathrm{l,s}}^{\text{output}} \\ E_{\mathrm{l,s}}^{\text{input}} = E_{\mathrm{l,(s-1)}}^{\text{output}} + r_{\text{consume}} \cdot d_l \\ E_{\text{charge}} = r_{\text{charge}} \cdot t_{\text{charge}} \\ E_{\mathrm{l,s}}^{\text{output}} \leq E_{\max} \\ E_{\mathrm{l,s}}^{\text{input}} \geq E_{\min} \\ \mathrm{US}_{\mathrm{l,s}} \begin{cases} \text{E-bus station} = 1 \\ \text{Fuel-bus station} = 0 \end{cases} \end{cases} \tag{5-10}$$

$$\min N_{T,\text{e-bus}} = \sum_{l=1}^{L} \mathrm{TUS}_l \cdot N_{l,\text{bus}}$$

$$s.t. \begin{cases} \\ H - \frac{2D_l}{v} + H \cdot \left(N_{l,\text{bus}} - 1\right) > \dfrac{2 \cdot r_{\text{consume}} \cdot d_l - \sum_{s=1}^{S} \cdot \mathrm{US}_{l,s} \cdot r_{\text{charge}} \cdot t}{r_{\text{charge}}} \end{cases} \tag{5-11}$$

Knowing the total number of charging infrastructures and e-buses required, we are able to calculate the total cost for the transformation, thereby knowing the amount of funds provided by the Government. The calculation is shown in Eq. (5-12).

$$F_{\text{Gov}} = \frac{N_{\text{infrastructure}} \cdot C_{\text{infrastructure}} + \sum_{l=1}^{L} \left(N_{l,\text{ bus}} \cdot C_{\text{bus}}\right)}{2} \tag{5-12}$$

Thus, to increase the utilization rate of the provided funding, we aim to find the maximum distance covered by the e-bus system. Our model is the following:

$$\max d_T = \sum_{l=1}^{L} \mathrm{TUS}_l \cdot d_l$$

$$s.t. \left\{ \sum_{l=1}^{L} \sum_{s=1}^{S} \left(\mathrm{US}_{\mathrm{l,s}} \cdot C_{\text{infrastructure}}\right) + \sum_{l=1}^{L} \left(\mathrm{TUS}_l \cdot N_{l,\text{bus}} \cdot C_{\text{e-bus}}\right) \leq F_{\text{Gov}} \right. \tag{5-13}$$

3. Model Data Specification

The data value of the variables in our model is demonstrated in Table 5-1. Most of our data is extracted from credible websites or articles. Yet, we also made assumptions for several values to make our model more realistic.

To decrease the waiting time for the passengers, we assume that the time spent on charging in charging stations is 0.0833 hours, which is 5 minutes. We also assume that the time lapse between departures is 0.3333 hours or 20 minutes. To promise safe traveling, we assume that the minimum battery capacity is 75 kWh and the average speed of the vehicle is 40 km/h.

Table 5-1: Static Parameters in Planning Model

Parameter	Symbol	Stockholm's Data
Maximum Battery Capacity (kWh)	E_{max}	250 [15]
Minimum Battery Capacity (kWh)	E_{min}	160[15]
Energy Consumption Rate (kWh/km)	r_{consume}	0.65 [15]
Charging Speed (kW/h)	r_{charge}	60 [15]
Cost per Electric Bus (SEK)	$C_{\text{e-bus}}$	4,196,602 [8]
Cost per Charging Infrastructure	$C_{\text{infrastructure}}$	2,115,000 [8]
Speed of Vehicle (km/h)	v	40
Time of Charging Layovers (h)	t_{charge}	0.0833
Time Lapse between Departures (h)	t_{depart}	0.3333

4. *Model Planning Results*

The results of our first two models (Eq. (5-10) , Eq. (5-11)) are 2259 charging sites and 2247 buses, respectively. This means that the overall transformation needs to install at least 2259 charging infrastructures and purchase at least 2247 e-buses. Using this data along with other data in Table 5-1, we calculate the total fund from the government using Eq. (5-12) . Then we use the final model (Eq. (5-13)), resulting in 5860.18 km. This resembles the total distance of the 117 out of 253 bus lines that will be transformed into e-bus lines in the first year. To accomplish such a transformation, 1297 charging infrastructures must be installed and 1297 buses must be purchased. Figure 5-3 represents the implementation.

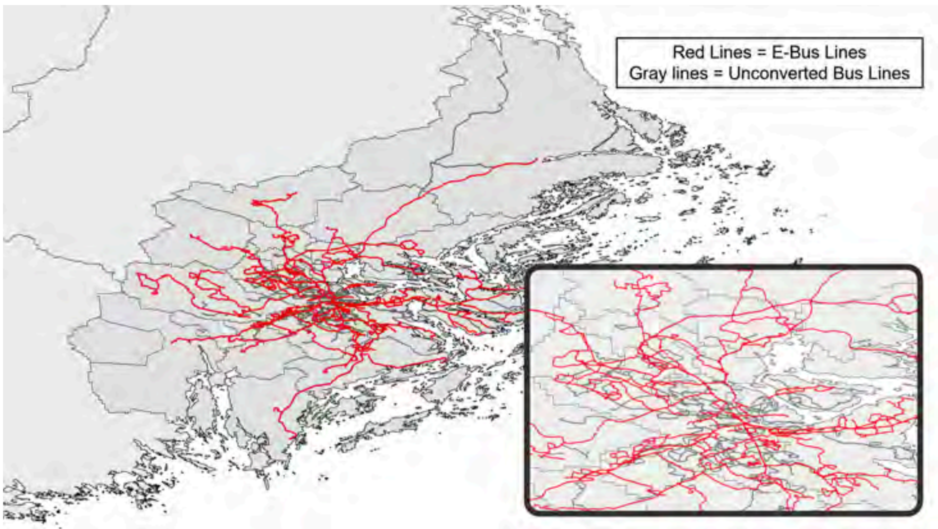

Figure 5-3: Year 1 Bus Line Map (Stockholm)

5. *Sensitivity Analysis*

To evaluate whether changing the capacity of the electric bus has an impact on the number of bus routes, number of e-buses, and number of chargers, we performed a series of sensitivity analyses. The electric bus capacity varies from 160 kWh to 250 kWh, so we stored the potential capacity in a matrice with increments of 10 kWh.

$$E_{\text{scale}} = \{160, 170, 180...250\} \tag{5-14}$$

E_{scale} represents the matrix of capacity values with the maximum and minimum capacity range.

For each capacity value, we perform optimization and store the results. Then, we plot the change in the number of stations, vehicles, and lines according to each capacity value. Below are the results of the analysis.

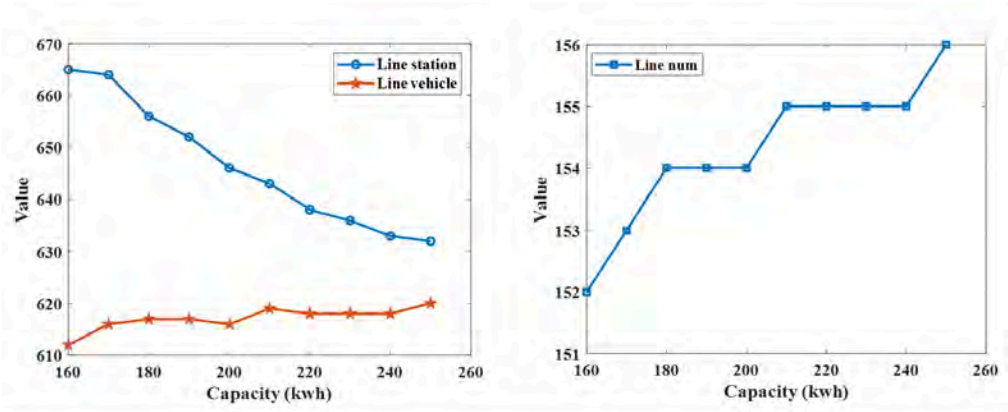

Figure 5-4: Results of Sensitivity Analysis

According to Figure 5-4, as the capacity of the bus increases, the number of vehicles and line numbers increase, but the number of stations decreases. Changing the bus capacity has a minor influence on these numbers because it affects the buses' charging time and dwelling time, thereby changing the bus line schedules.

VI. GENERATIVE INCOME OPTIMIZATION AND TIMELINE

1. Problem Objective

To further the significance of our planning model and apply it to a more sustainable application, we incorporated consideration of the timeframe for our implementation. Specifically, the implementation process will be spread over a 10-year timeframe. However, considering the fact that external funding is presumably only 50% of the money for the implementation, we will develop our planning model by incorporating generative income measures. Specific changes are shown in the following developed flowchart.

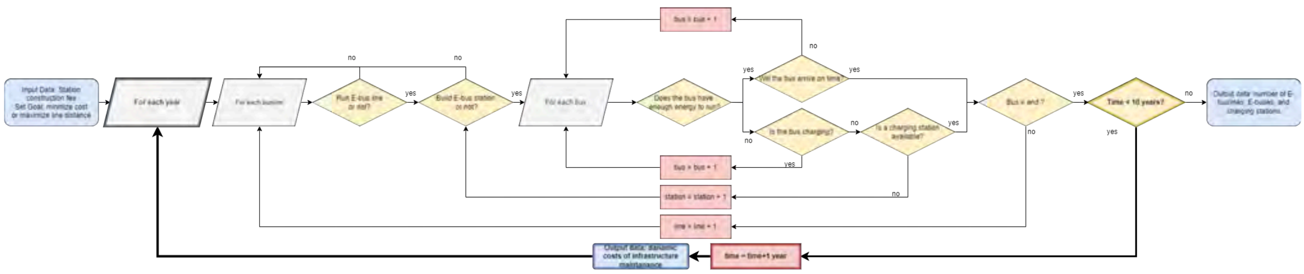

Figure 6-1: Generative Income Optimization Model Flow Chart

2. Explanation of Model

Generative income refers to the amount of income generated by the bus system itself and the amount of operation cost that could be saved from this implementation process. Specifically, income generated by the bus system generally refers to the income coming from tickets, while operation cost saved from this implementation process mainly deals with profit that is gained due to the lower fuel price of electric buses compared to the fuel price of diesel buses.

Specifically, annual ticket income could be represented by the product of the average ticket price and the total number of riderships in a year, while the profit gained from the difference in fuel price could be gathered by adding up the amount of distance traveled by e-buses that work on electric bus routes that would otherwise be using diesel buses if the project is not implemented. Thus, Eq. (6-1) would show the calculation for generative income.

$$I_{\text{gen}} = P_{\text{ticket}} \cdot n_{\text{ridership}} + \sum_{l=1}^{l} \left[(C_{\text{diesel}} - C_{\text{elec}}) \cdot d_l \cdot n_{l,\text{bus}} \cdot n_{l,\text{shifts}} \cdot \text{TUS}_l \right], \tag{6-1}$$

Generative income will be invested in next year's implementation, providing next year's "fund" that restricts the financial cost of next year's implementation. However, there is one thing to consider: the operation cost of buses for maintenance, staff employment, etc. Therefore, part of the generative income would have to be used to bear the operation cost of the system, while the other part of the generative income would be invested into the project and counted as part of next year's funding. Therefore, Eq. (6-2) could be established to include generative income in our planning model.

$$F_{\text{disposable}} = P_{\text{ticket}} \cdot n_{\text{ridership}} + \sum_{l=1}^{l} \left[(C_{\text{diesel}} - C_{\text{elec}}) \cdot d_l \cdot n_{l,\text{bus}} \cdot n_{l,\text{shifts}} \cdot \text{TUS}_l \right] - C_{\text{op}} \tag{6-2}$$

$F_{\text{disposable}}$ represents the amount of funds invested in next year's implementation process that could be directly used.

With the function of generative income and disposable funding for the next year established, we can now implement this implementation process over the 10-year timeframe. Specifically, $F_{\text{disposable}}$ would replace F_{Gov} in the restrictions of our planning model. Then, we will loop our planning model annually (10 times in total), concurrently refreshing the value of $F_{\text{disposable}}$ every time we start calculation for a new year and setting data setpoints at year 1, year 3, year 6, and year 10 to gather results. As a result, we would be able to model the entire implementation process with specific optimized electric bus routes and charging infrastructure data under realistic financial constraints.

3. Model Data Specification

In Eq. (6-2), some of the parameters are numbers that (we assume) stay constant over time, meaning that they are known numbers that would not shift according to the progress of our implementation. To quantify the amount of e-bus travel on one line, we assume the number of buses times the number of shifts to be 19710. These static parameters are shown in the following table:

Table 6-1: Additional Static Parameters in Developed Model

Parameter	Symbol	Stockholm's Data
Ticket Price (SEK)	P_{ticket}	30 (on average) [16]
Annual Ridership (number of people)	$n_{\text{ridership}}$	237,000,000 [17]
Cost of Oil (SEK/km)	C_{diesel}	5.714 [18]
Cost of Electricity (SEK/km)	C_{elec}	0.172
The Number of Buses times the Number of Shifts (times)	$n_{l,\text{bus}} \cdot n_{l,\text{shifts}}$	19,710
Cost of Operation (billion SEK)	C_{op}	6.65 [19]

4. Model Planning Results

With our incorporation of Eq. (6-2) in the planning model, optimization under our new financial constraint - generative income - could be found. The data gathered from our data setpoints will be able to provide a detailed roadmap of the implementation process according to our model.

a. *Distribution of Bus Routes - Temporal Variation:*

Year 1. Since we assume there have been no electric routes implemented at the start of our implementation process, both I_{ticket} and I_{replace} are not available sources of our income in the first year. There would be no additional income generated by the bus system itself to be added to our F_{Gov} according to Eq. (6-1). Thus, the first year's F_{Gov} would be the same as the F_{Gov} that we modeled as our restriction method in Eq. (6-13). This means that the result of our developed model at our Year 1 data setpoint will be the same as the result of our model in question 2, which could referred to in *section V.4*.

Year 3. At year 3, 145 bus lines out of the 253 total are converted for electric buses. This means an increase of 28 more electric bus lines these two years that are merely funded by generative income from the bus system itself. Additionally, this will cover a total distance of 6959.49 km, an increase of 1099.32 km compared to our data from the last data setpoint. At the same time, 1547 charging sites have been constructed and the same number of e-buses are in operation, marking an increase of 250 charging sites and e-buses to further the implementation process. Figure 6-2 represents these changes.

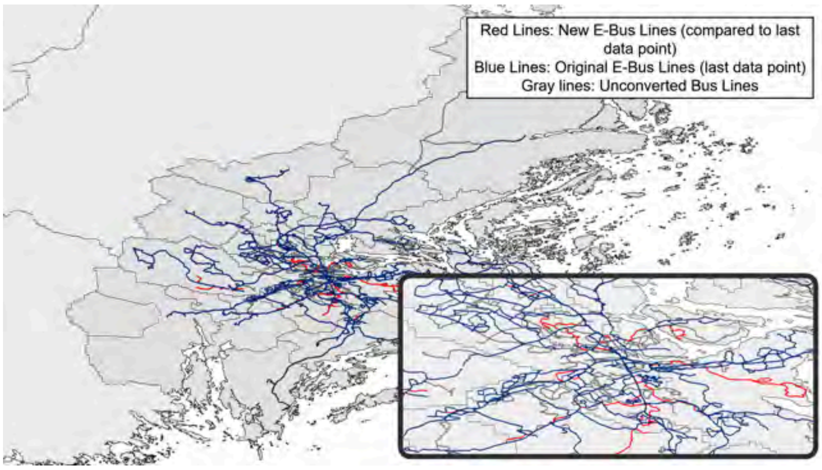

Figure 6-2: Year 3 Bus Line Map (Stockholm)

Year 6. One year after half of the implementation plan, 197 bus lines out of the 253 total have become electric bus lines with charging infrastructures equipped on them, covering 8522.77 km of transit distance. Over the three years, 52 more electric bus lines were constructed and 1563.28 more km were replaced with eco-friendly transits. Just as expected, both the number of charging infrastructures built and the number of e-buses put into operation further increased by 372 to 1919 charging infrastructures. Figure 6-3 represents the map of year 6.

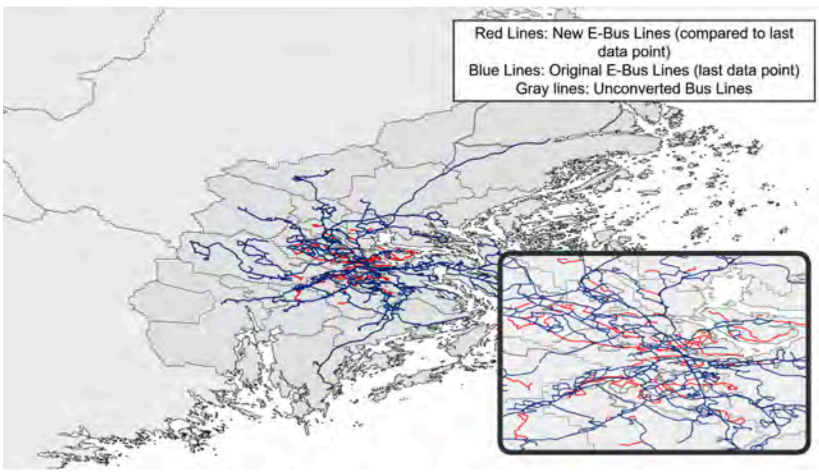

Figure 6-3: Year 6 Bus Line Map (Stockholm)

Year 10. At the end of our implementation process, all 253 bus lines have become electric-based with 2259 charging stations and 2247 e-buses in operation. The bus lines would cover a total distance of 9726.32 km. Figure 6-4 presents the end result of our implementation process.

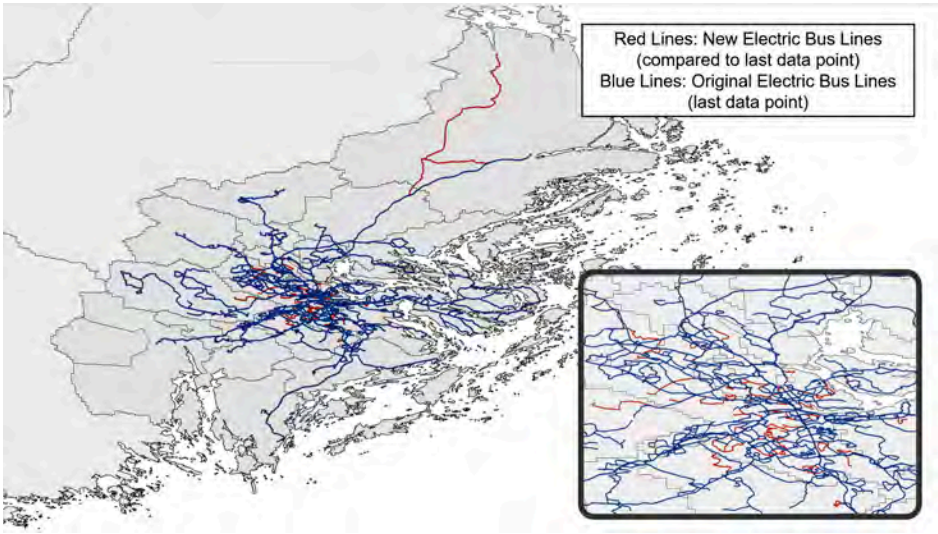

Figure 6-4: Year 10 Bus Line Map (Stockholm)

b. *Overall Trend:*

Overall, after we incorporated consideration of generative income, the number of electric bus lines, the number of charging infrastructure, and the distance covered by electric transit have all shown an increasing trend, which proves that the implementation process has successfully converted the bus system.

Specifically, the gradual change in the number of electric bus lines, the number of charging sites, and the distance covered by our implementation are shown below.

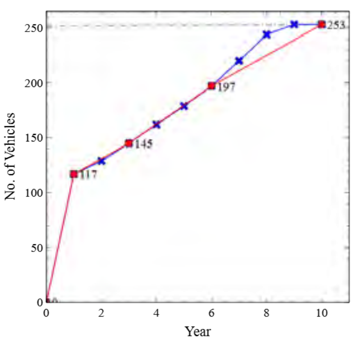

Figure 6-5: Number of E-Bus Lines (Stockholm)

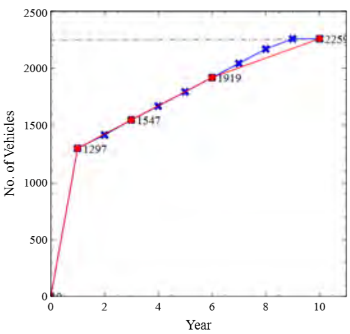

Figure 6-6: Number of Chargers (Stockholm)

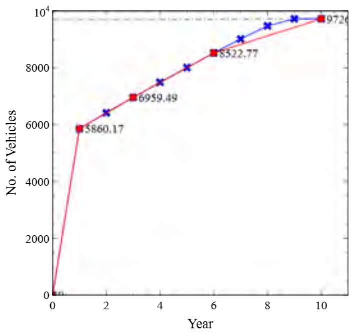

Figure 6-7: Distance Covered (Stockholm)

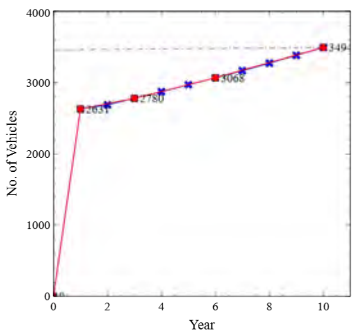

Figure 6-8: Number of Vehicles (Stockholm)

5. Application

The situations and constraints faced by bus systems are mostly similar across cities. Thus, our models are also applicable to other metropolitans. For a sample, we use our model to simulate the transformation of bus systems in Chicago, Illinois, and Shanghai, China. We would maintain our assumption that the government will provide a fund that is 50% of the total transformation cost. The data collected and used are shown in Table 6-2 below.

Table 6-2: Static Parameters of Model in Chicago and Shanghai

Parameter	Symbol	Chicago's Data	Shanghai's Data
Maximum Battery Capacity (kWh)	E_{max}	220 [20]	355 [21]
Minimum Battery Capacity (kWh)	E_{min}	66	106.5
Energy Consumption Rate (kWh/km)	r_{consume}	1.25 [20]	1 [21]
Charging Speed (kW)	r_{charge}	73 [20]	100 [21]
Cost per Electric Bus	$C_{\text{e-bus}}$	752,000 (USD) [22]	2,500,000 (CNY) [21]
Cost per Charging Infrastructure	$C_{\text{infrastructure}}$	251,990 (USD) [8]	1,633,095 (CNY) [8]
Speed of Vehicle (km/h)	v	40	40
Time of Charging Layovers (h)	t_{charge}	0.0833	0.0833
Time Lapse between Departures (h)	t_{depart}	0.3333	0.3333
Ticket Price	P_{ticket}	2 (USD) [23]	2 (RMB) [24]
Annual Ridership (number of people)	$n_{\text{ridership}}$	237,280,000 [25]	868,080,000 [26]
Cost of Oil	C_{diesel}	0.27 (USD/km) [27]	0.55 (CNY/km) [28]
Cost of Electricity	C_{elec}	0.19 (USD/km)[29]	0.15 (CNY/km) [28]
The Number of Buses times the Number of Shifts (times)	$n_{l,\text{bus}} \cdot n_{l,\text{shifts}}$	19,710	19,710
Ticket Income	I_{ticket}	293,900,000 (USD) [30]	1,736,160,000 (CNY)
Cost of Operation	C_{op}	133,980,000 (USD)	957,000,000 (CNY)

For Chicago, we applied our model to simulate 127 bus lines in the city. Bus lines extending out of the city and special bus lines are excluded from the data for the convenience of calculation. The results are shown below.

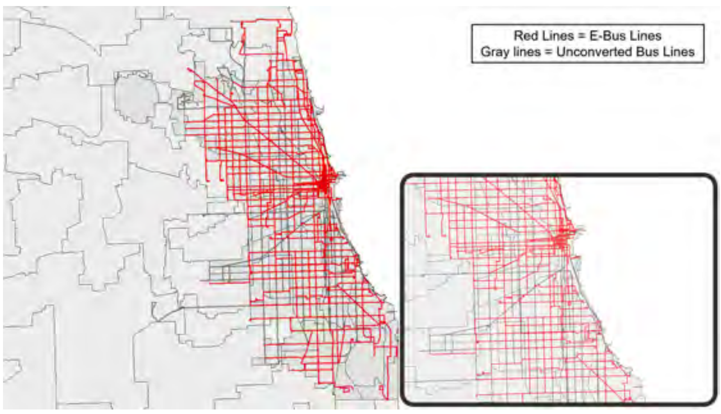

Figure 6-9: Year 1 Bus Line Map (Chicago)

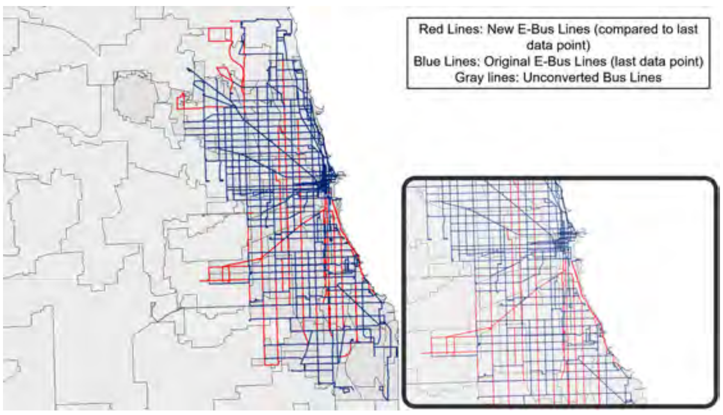

Figure 6-10: Year 3 Bus Line Map (Chicago)

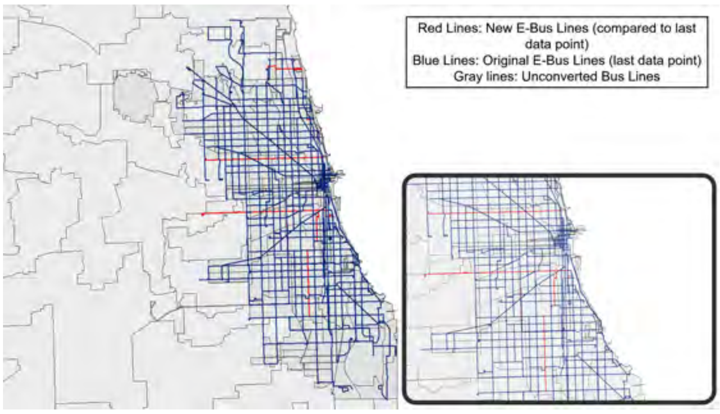

Figure 6-11: Year 6 Bus Line Map (Chicago)

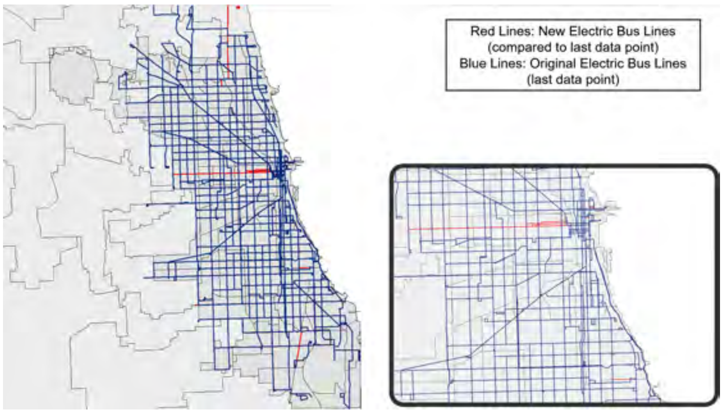

Figure 6-12: Year 10 Bus Line Map (Chicago)

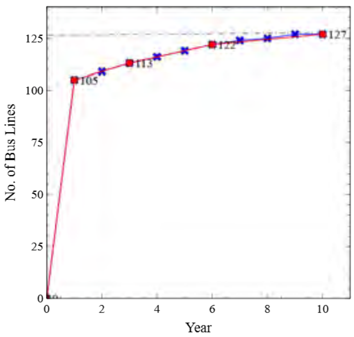

Figure 6-13: Number of E-Bus Lines (Chicago)

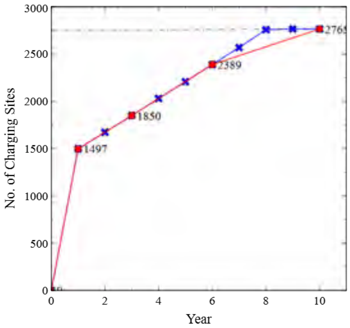

Figure 6-14: Number of Chargers (Chicago)

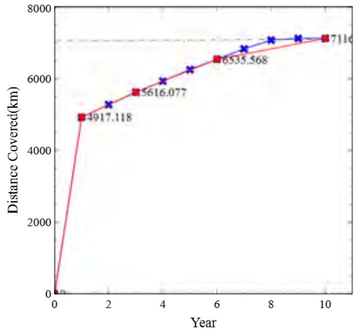

Figure 6-15: Distance Covered (Chicago)

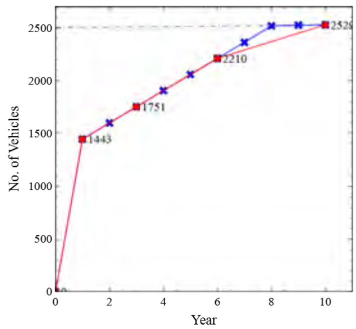

Figure 6-16: Number of Vehicles (Chicago)

Within the ten-year period, the number of transformed bus lines gradually increases until the end of year nine, when every bus route is completely transformed. The total distance covered by the e-bus lines at the end of the day would be approximately 7117 km, with a total of 127 lines, 2765 infrastructures, and 2526 e-buses in the operation.

We then applied our model to simulate 1240 bus lines in Shanghai. Again, bus lines extending out of the city and special bus lines are excluded for the convenience of calculation. The following figures present the modeled results.

Figure 6-17: Year 1 Bus Line Map (Shanghai)

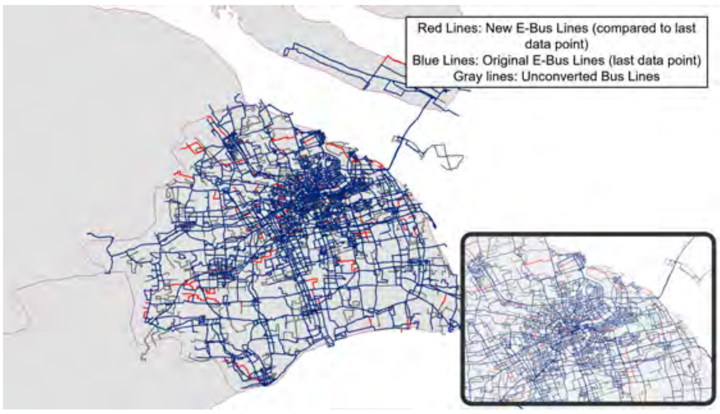

Figure 6-18: Year 3 Bus Line Map (Shanghai)

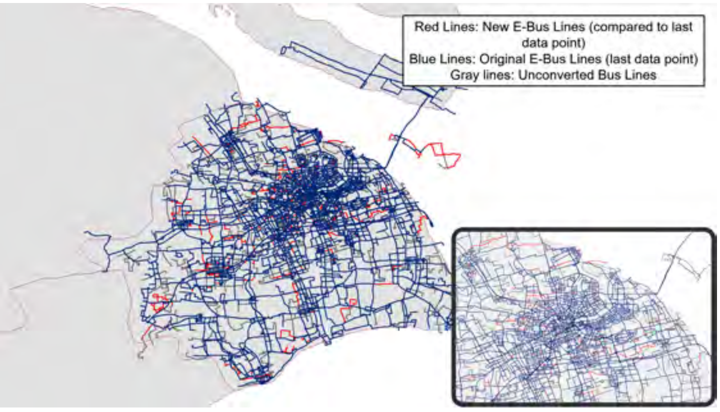

Figure 6-19: Year 6 Bus Line Map (Shanghai)

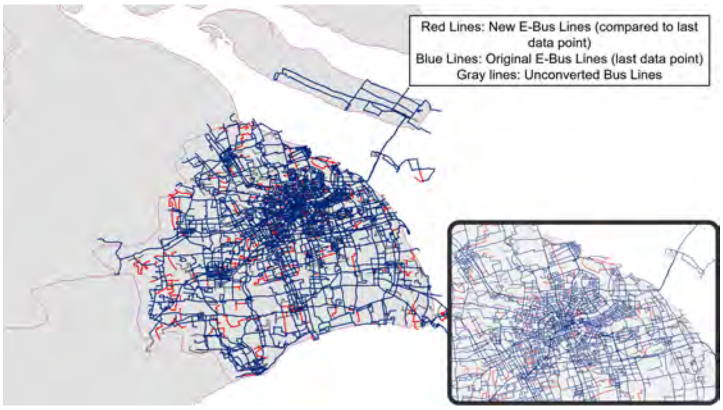

Figure 6-20: Year 10 Bus Line Map (Shanghai)

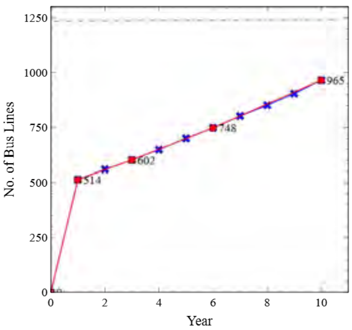

Figure 6-21: Number of E-Bus Lines (Shanghai)

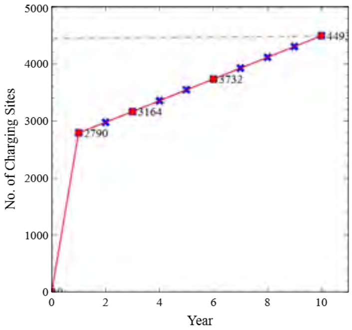

Figure 6-22: Number of Chargers (Shanghai)

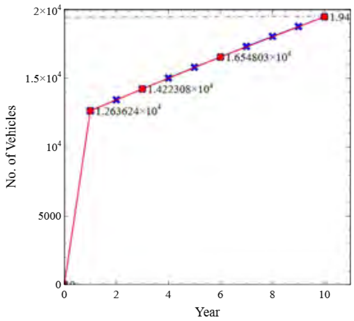

Figure 6-23: Distance Covered (Shanghai)

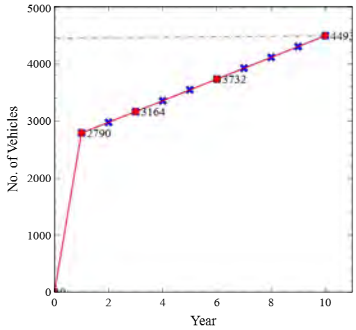

Figure 6-24: Number of Vehicles (Shanghai)

Within ten years, the number of transformed bus lines nearly doubled with the incorporation of generative income, reaching a total of 965 transformed bus lines that covered approximately 19479 km by the end of the period. 4493 charging infrastructures are installed and 4493 e-buses are purchased to operate these 965 bus lines.

While both Stockholm and Chicago completed the transformation by the end of the ten years, Shanghai only finished 77.82% of the entire transformation. One possible explanation is that there are too many bus lines in Shanghai, numbering up to five times the total number of bus lines modeled in Stockholm and ten times the total number of bus lines modeled in Chicago. At the same time, Shanghai's bus system raises relatively low ticket prices, minimizing the profit generated by the bus system throughout the implementation process. But overall, the change in the number of bus-line covered each year after the first year is increasing in all three cities. And since this change varies directly with the profit of the bus system, we concluded that the transformation profits the bus system in the long term. Furthermore, replacing the traditional diesel bus with e-buses has ecological benefits. Hence, the transformation will ultimately boost the general welfare in all urbanized cities.

VII. EVALUATION OF STRENGTHS AND WEAKNESSES

1. Strengths

Our first model evaluates the ecological consequences of bus fleets using different fuels using the TOPSIS and Entropy Weight Method. While the TOPSIS method reflects underlying variables' influences on the local ecology, the Entropy Weight method guarantees our objectivity while assessing the variables.

Using the integer programming method, our second model evaluates the economic consequences for the local transportation department to convert to an all-electric fleet. This programming method allows us to specify our model for each route and bus to estimate the precise number of bus lines, e-buses, and charging stations the department needs to implement.

Furthermore, we added a dynamic calculation of income and costs for multiple cities to construct an E-Bus system by crafting a 10-year roadmap. We replicated this model in Shanghai, Stockholm, and Chicago to demonstrate our roadmap's quality and feasibility, proving our models' robustness and consistency.

2. Weaknesses

There might be some inaccuracies in our data samples due to estimations. For instance, our model did not consider the actual daily schedule of the buses. Instead, we calculated the frequency for a bus to arrive ourselves. Some of our data samples might need to be updated in other maps and schedules.

Furthermore, our justified assumptions might add slight inaccuracies to our models. For instance, we generalized that only quantifiable ecological variables are included in the three models. However, different cities have different geographical environments that subtly affect the bus systems. Hence, it is hard to quantify their influences on the operation of the bus systems and might create some inaccuracies.

VIII. CONCLUSION

In conclusion, our models, rooted in both ecological and economic perspectives, advocate for the widespread adoption of all-electric bus fleets in metropolitan areas. The TOPSIS associated with the Entropy Weight Method employed in the ecological assessment underscored the superior environmental performance of electric buses. The Zero-one Integer Programming model, considering budget constraints and generative income, strategically maximized ecological benefits while minimizing costs in the implementation process.

Furthermore, our models extend beyond Stockholm to global metropolitans like Chicago, USA, and Shanghai, China. Our future endeavors involve refining data accuracy by incorporating actual daily bus schedules, addressing city-specific variables, and so on to improve our model. Continuous updates to variables, data samples, and refining assumptions will enhance the robustness of our models, contributing to a sustainable and ecologically conscious future in public transportation.

IX. ONE-PAGE LETTER

HIMCM Team #13904
November 14th, 2023

To,
Lena Erixon
Director General of Trafikverket
Borlänge, Sweden

Dear Ms. Erixon,

I am writing on behalf of a group of passionate students who are using mathematical models to simulate environment-friendly policies' real-life consequences. We would like to raise your awareness of an important initiative that could substantially benefit the well-being of Stockholm's community and environment: converting city buses to an all-electric fleet.

The increasing severity of urban air pollution lately has been alarming worldwide. Sweden, a leader in many fields of environmental policies and an active participant in the EU's works to reduce air pollution, has a cooperative government and innovative technologies in addressing ecological issues. A conversion to electric buses presents an opportunity for Stockholm to reduce carbon emissions, improve air quality, reduce noise pollution, and act as a role model of energy source transformation for all other EU member states.

The adoption of this proposal is imperative from all perspectives. Ecologically speaking, driving electric buses reduces the city's carbon emission and noise pollution than driving gasoline or biofuel-fueled buses. Economy-wise, electricity is a cheap and efficient resource that could be an excellent substitute for fuel in the public transportation system. From these two perspectives, our team has thoroughly analyzed the feasibility and benefits of converting to electric buses. Below are our results.

First, we adopted the TOPSIS analysis and Entropy Weight Method to compare the ecological influences of adopting an all-gasoline, all-biodiesel, all-biogas, or all-electric bus fleet in Stockholm. After comparing these four types of buses' CO_2 emissions during drives, CO_2 emissions when producing energy, noise pollution, and net energy consumption, we found an electric fleet to be the most ecologically friendly, substantially decreasing the pollution levels.

Then, we construct a model focusing on the financial implications of a conversion to e-buses. It factors in an external fund that covers up to 50% of the transition costs by rebuilding the city bus system with a limited budget. Using integer programming, we present you two ways to approach this proposal that can either economically minimize the electric bus costs or strategically maximize the number of bus routes covered by E-buses.

Finally, if you are interested in our simulations, our article includes a 10-year roadmap for Stockholm's gradual transition to a fully electric bus fleet by 2033. This blueprint considers the dynamic costs of converting the bus type over a period of 10 years, and it can help you to supervise and schedule the implementation and construction of E-bus lines and stations by time.

It will be a great honor if you will adopt our roadmap in the future. The benefits of this conversion extend beyond environmental advantages, for adopting an all-electric fleet can significantly decrease ecological damages done by the prior public transportation system and help establish Sweden's role model figure in front of all other European nations.

Sincerely,
HIMCM Team #13904

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