REDUCING CARBON EMISSIONS IN MESA, ARIZONA

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ABSTRACT

The Phoenix metropolitan area has experienced sustained growth in population and economic activity over the past decade. While this expansion signals progress, it also exacerbates existing environmental challenges, notably declining air quality and intensifying summer heat. These climate impacts disproportionately affect vulnerable populations, including the elderly, low-income communities, and the unhoused—many of whom lack access to adequate cooling, healthcare, or reliable transportation.

Addressing such complex issues requires systemic change, but targeted local interventions can serve as effective entry points. Public transportation, in particular, represents a practical and scalable lever for reducing greenhouse gas emissions, improving accessibility, and promoting equitable urban development. This report presents a comprehensive analysis of Mesa, Arizona's current public transit infrastructure, with the goal of identifying service gaps and proposing sustainable expansion strategies.

Using a combination of temperature and ridership trend analysis, geospatial modeling in QGIS, and emissions-based impact forecasting, this project proposes five new bus routes designed to increase service coverage in underserved areas. Additionally, the report evaluates potential environmental benefits and operational costs, offering a framework for integrating public transit improvements into broader climate resilience planning.

Introduction

Urban growth in the American Southwest brings with it a complex tradeoff between economic opportunity and environmental strain. The Phoenix metropolitan area, including Mesa, has expanded rapidly, fueled by low unemployment and relatively affordable housing. But this growth has worsened regional challenges such as poor air quality, urban heat island effects, and overdependence on private vehicles. These conditions not only accelerate greenhouse gas emissions but create serious health risks—especially for low-income, elderly, and unhoused populations with limited access to climate-controlled environments or transportation options.

Public transportation sits at the intersection of many of these issues. In cities like Mesa, which are built primarily for cars, expanding public transit offers an opportunity to reduce emissions, increase mobility equity, and build local climate resilience. Yet these systems often lag behind population growth, leaving newly developed or peripheral areas without sufficient service.

This report explores whether targeted expansions in Mesa's bus network could help address these overlapping challenges. Rather than pursue a broad or symbolic net-zero goal, the project focuses on one concrete question: how can we reconfigure public transportation to serve more people while reducing emissions? By combining geospatial analysis, demographic data, emissions modeling, and budgetary research, the report presents an actionable framework for data-driven transit development in Mesa.

Data Sources

This project utilized a wide range of datasets, covering public utilities, climate records, transit usage trends, budget documents, and geospatial data layers. These sources informed both the direction and the execution of our analysis, helping us define project scope, identify gaps in public infrastructure, and model the impact of proposed interventions.

1. **City Electricity Use and Solar Panel Infrastructure (City of Mesa Open Data Portal, 2015–2023):**
   Our early research began with a large dataset detailing energy consumption across city-owned infrastructure. This

dataset included records for various site types (e.g., buildings, traffic signals, parks, water facilities). Included attributes like site type, EMS installation dates, and solar panel usage. Helped frame the city's current energy practices and revealed limited solar infrastructure adoption despite favorable climate conditions.

2. **Historical Weather Data (2013–2023):**
   To investigate the connection between climate stressors and public transit usage, we pulled daily minimum and maximum temperature data for Mesa from the Open-Meteo API. This provided over 10 years of continuous daily climate records. The data was converted from JSON to CSV for use in pandas-based time series analysis.
   Our goal was to examine long-term trends in summer heat severity and explore whether extreme temperature events might correspond with declines in transit ridership. The dataset revealed significant seasonal variability, with increasingly intense summers in recent years—supporting our decision to treat heat and accessibility as linked policy concerns in our transit analysis.
3. **Public Bus Ridership Data (2013–2023):**
   To understand how transit usage patterns have changed over time, we analyzed monthly ridership data for Mesa's bus system from July 2013 to the present. This dataset was sourced from Valley Metro via the City of Mesa's open data portal and included:
   1. Monthly total boardings across all routes
   2. Annotations for COVID-era service reductions
   3. Seasonal patterns in usage

   We observed a consistent dip in ridership during the summer months—coinciding with peak heat—which helped us frame climate vulnerability as a barrier to transit use. These insights influenced the decision to prioritize accessibility improvements in underserved, high-temperature areas of the city.

4. **Municipal Budget Reports (FY2022–2024):**
   To assess the financial feasibility of expanding the bus network, we reviewed the City of Mesa's annual transportation budgets and general fund allocations. These documents offered insight into:
   1. Existing public transit operating costs
   2. Bus procurement and maintenance expenditures
   3. Capital funding priorities

   This analysis allowed us to produce rough cost estimates for our proposed routes and stops, ensuring that our recommendations were not only environmentally motivated but grounded in fiscal realism.

5. **Geospatial and Demographic Data for GIS Analysis:**
   The core spatial analysis component of this project relied on publicly available GIS datasets, including:
   1. Census Tracts: TIGER/Line shapefiles from the U.S. Census Bureau, used to define boundaries for demographic analysis.
   2. ACS 5-Year Population Estimates: Total population data aggregated at the tract level, cleaned in Excel for compatibility with GIS operations.
   3. Transit Routes and Stops: Shapefiles and CSVs used to visualize the existing bus network and later digitize proposed routes.
   4. OpenStreetMap Base Map: Provided contextual geography for visualizing route placement and population overlays within QGIS.

   These spatial layers were foundational for performing buffer analysis, tract-route intersections, and population impact modeling.

6. **Data Transparency:**
   All datasets were publicly available and sourced from open APIs or government data portals. This ensured transparency, replicability, and minimized private-sector bias.

Methodology
Forecasting Temperature

To investigate long-term temperature trends in Mesa and assess the potential impact of climate conditions on public transit usage, we implemented two time-series forecasting models: a Long Short-Term Memory (LSTM) neural network and an ARIMA (AutoRegressive Integrated Moving Average) model. These models were applied to historical daily temperature data obtained from the Open-Meteo API, spanning over 10 years.

LSTM Model (Short-Term Forecasting): For short-term prediction, an LSTM neural network was developed using TensorFlow. The dataset included columns for date, minimum temperature, and maximum temperature. A new column was engineered to represent the daily average temperature, computed as the mean of the minimum and maximum values.

The data was then converted to a datetime format and preprocessed for modeling. This included reshaping and normalization to the range [0, 1], which is a common practice for improving neural network convergence. The dataset was split into training and testing sets with an 80:20 ratio.

After testing multiple architectures, the final model consisted of two LSTM layers with 50 units each. The Adam optimizer was used for training, and mean squared error (MSE) was selected as the loss function, given its suitability for regression tasks. Through hyperparameter tuning, the final model was trained for 20 epochs with a batch size of 16, as further increases showed negligible improvement in validation error.

The model was trained on historical sequences and used iteratively to forecast the next 30 days of average temperature. Results were visualized using `matplotlib`, allowing direct comparison of predicted and actual values.

ARIMA Model (Long-Term Forecasting): For longer-term forecasting, an ARIMA model was constructed using the `statsmodels` library. The preprocessing steps were largely similar to the LSTM workflow, with the exception that the data was truncated at December 31, 2024. This cutoff allowed the model to generate forecasts for the subsequent five years, beginning in 2025.

The ARIMA model was configured without moving average (MA) components and focused solely on autoregressive (AR) and differencing elements. The model was trained on the average temperature column, and predictions were generated through 2029. Visualization was again done using `matplotlib`.

Model performance was assessed using root mean squared error (RMSE) and mean squared error (MSE), which were calculated as 0.387 and 0.362, respectively. These low values indicate strong predictive performance and minimal deviation from actual observed values, suggesting high consistency and a low presence of outliers in the model's forecasts.

Financial Review

As part of the project's feasibility assessment, we conducted a financial review of the City of Mesa and Valley Metro's transportation-related budget allocations. This analysis was based on publicly available fiscal year budget reports from 2022 through 2024. Although not structured as a dataset, these documents provided detailed breakdowns of current expenditures, departmental funding priorities, and planned capital improvements.

The review focused on operational budgets, personnel and maintenance costs, and infrastructure investments related to Mesa's public transit system. By examining historical trends and current allocations, we were able to identify areas that are consistently underfunded—particularly in fleet maintenance and driver personnel.

Informed by this budgetary context, we proposed a theoretical reallocation model that increased funding for high-impact categories such as maintenance and route operations. Our objective was to demonstrate that strategic investment in these areas could enable the proposed route expansion without necessitating a dramatic overall increase in budget. Moreover, by aligning route planning with existing funding priorities, we aimed to present a realistic implementation pathway that balances service improvement with fiscal responsibility.

GIS-Based Route Planning

The primary objective of the GIS component was to identify census tracts underserved by public transportation and to visualize proposed route expansions aimed at increasing transit accessibility, reducing car dependency, and promoting sustainability. QGIS 3.4, an open-source geographic information system, was used as the primary platform for spatial analysis, symbology, and map production. Microsoft Excel was employed for preprocessing demographic data, while U.S. Census Bureau and City of Mesa datasets provided the foundation for tract-level and transit infrastructure inputs.

This GIS methodology provided a spatially grounded, data-driven approach to identifying accessibility gaps and proposing feasible infrastructure solutions. By leveraging attribute joins, spatial selection tools, manual digitization, buffering, and population modeling, we developed a replicable framework for transit planning at the urban scale. The methodology is organized into six key phases:

1. **Data Acquisition and Preparation:** Shapefiles for all Arizona census tracts were obtained from the U.S. Census Bureau's TIGER/Line database. These were clipped using Mesa's municipal boundaries to isolate tracts within the city. Population data from the ACS 5-Year Estimates (Table B01003) was cleaned and formatted in Excel. The GEOID field was standardized to align with the tract shapefile, enabling a successful attribute join in QGIS.
   Public transit data—including existing bus route shapefiles and stop locations—was imported and spatially verified against OpenStreetMap base layers. All vector layers were projected to a consistent coordinate reference system to ensure spatial compatibility.
2. **Spatial Join and Choropleth Mapping:** Population estimates were joined to the tract shapefile via the GEOID key, creating a composite layer. A choropleth map was produced using graduated symbology to visualize population density, classified using natural breaks (Jenks) or quantiles. This visualization highlighted high-density tracts that were prioritized for proposed route extensions.
3. **Transit Coverage Gap Analysis:** Using QGIS's "Select by Location" tool, tracts intersecting with existing transit routes were selected and extracted. The selection was inverted to isolate tracts with no overlapping service. These tracts—primarily located in the northeastern and southeastern quadrants—were exported and styled as a separate layer to clearly communicate service gaps in the current network.
4. **Proposed Route and Stop Design:** A new line layer was digitized to map six proposed bus corridors, strategically drawn to serve underserved tracts while aligning with major roadways and avoiding redundant coverage. Stops were manually added by extracting vertices along each route, generating point features that represent proposed bus stops. These were styled with circular markers and labeled for visibility.

5. **Map Refinement and Visualization:** Final map production involved rule-based symbology and layer transparency adjustments. Proposed routes were given unique colors and widths for distinction, while base layers and census tracts were styled to maintain readability. Population overlays, coverage gaps, and proposed infrastructure were integrated into a single, high-contrast visual suitable for reports and presentations.
6. **Accessibility Buffer Analysis and Population Impact Estimation:** To evaluate the effectiveness of the proposed routes, a walkability buffer was created around each line feature using QGIS's buffer tool. A uniform distance of 500 meters was applied—representing a 5–7 minute walk—to simulate the realistic serviceable area for pedestrians.
   This buffer layer was then intersected with the Mesa census tracts layer to determine which geographic areas were newly served by the proposed routes. For each intersecting tract, an *overlap_ratio* attribute was calculated by dividing the area of overlap by the total tract area. Only tracts with at least 20% overlap were considered meaningfully served.
   A new attribute, *pop_contributed*, was calculated by multiplying each tract's population by its *overlap_ratio*. This generated a weighted estimate of the population affected by the new routes. Summing this attribute across all qualifying tracts yielded a final estimated total of **63,414 people** who would gain access to public transit within walking distance.

Results and Visualizations

Bus Ridership Trends

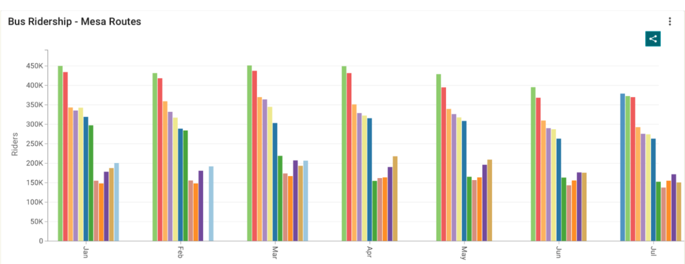

FIGURE 1. Monthly Bus Ridership Trends in Mesa (2014–2023)

Figure 1 displays the monthly bus ridership patterns in Mesa from January 2014 through the most recent data available. The visualization highlights the months of January through May, with each group of bars representing the same month across consecutive years (e.g., the leftmost green bars show January 2014–2023, followed by February, and so on).

While not shown here, similar patterns are observed in the remaining months of the calendar year. Notably, ridership consistently drops during the summer months—particularly June and July—before rising again in August. This trend likely correlates with academic calendars, as many schools adjourn in May and resume in August.

A sharp decline is evident beginning in March 2020, when ridership dropped from approximately 283,000 riders in February 2020 to just 154,000 by April 2020. This decrease aligns with the onset of the COVID-19 pandemic and subsequent lockdown measures, which led to the suspension of in-person schooling, office closures, and a general decline in daily commuting.

Although ridership has gradually recovered since the peak of the pandemic, it has not yet returned to pre-2020 levels. The persistence of remote work, post-pandemic relocation patterns, and potential economic instability may all contribute to this plateau, though further research would be needed to assess the long-term drivers of transit demand.

Weather Forecasting

To understand long-term climatic shifts and their implications on transit infrastructure, we used weather data from a public API to perform two forecasting tasks: short-term prediction for the next 30 days, and long-term forecasting for the next 5 years.

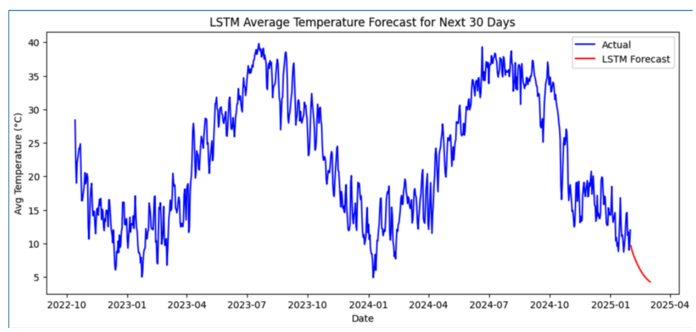

FIGURE 2. LSTM Forecast: Daily Temperature Trends in Mesa (Next 30 Days)

Figure 2 shows the short-term temperature forecast generated using an LSTM (Long Short-Term Memory) neural network. The model was trained on 10 years of historical daily temperature data, normalized and reshaped for time-series analysis. The forecast was conducted in February 2025 to predict the remainder of the month. Once actual February temperatures were available, we compared them with our predictions — validating the model's reliability. Evaluation metrics such as mean squared error (MSE) and root mean squared error (RMSE) showed strong performance, with RMSE below 0.4 C, indicating minimal deviation from actual values.

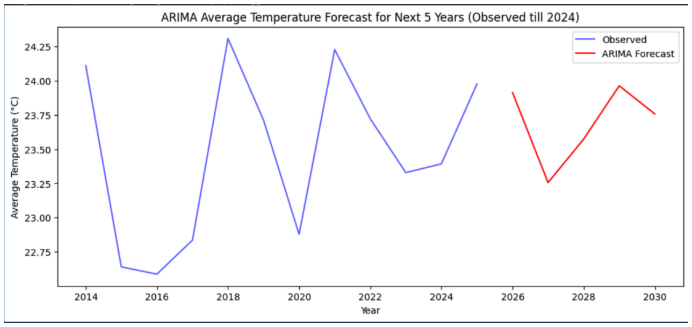

FIGURE 3. ARIMA Forecast: Average Yearly Temperature in Mesa (2025–2029)

Figure 3 shows our long-term temperature forecast using the ARIMA model. This method, trained on yearly average temperatures up to 2024, projected a fluctuating "zig-zag" pattern consistent with regional climate variability. Nevertheless, a gradual warming trend is evident — with an overall increase of approximately 0.5 F expected by 2029. The model's accuracy was supported by low MSE and RMSE values (0.362 and 0.387 respectively), which reflect both precision and consistency across forecasted values.

These temperature forecasts supported our project's emphasis on sustainability and carbon mitigation — highlighting how projected warming could amplify the need for reduced car dependency and increased access to efficient public transit.

Geographic Information System

This section presents the GIS analysis conducted to identify transit service gaps in Mesa, AZ, and visualize proposed interventions. Using population distribution, spatial joins, and buffering techniques, we were able to assess current accessibility and simulate the impact of new bus routes.

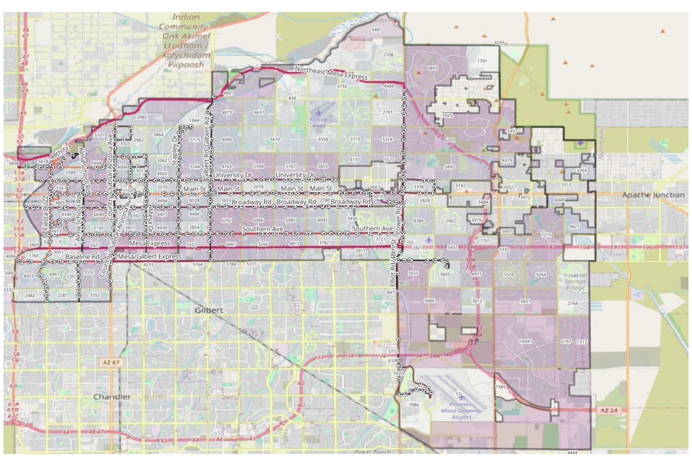

FIGURE 4. Existing Bus Routes and Stops in Mesa

Existing Transit Coverage Figure 4 illustrates the current state of Mesa's public bus infrastructure. The routes are concentrated in the central and western parts of the city, leaving large portions of the northeastern and southeastern areas underserved. Bus stops are densely clustered in certain zones but absent in major residential regions, suggesting inequitable transit access.

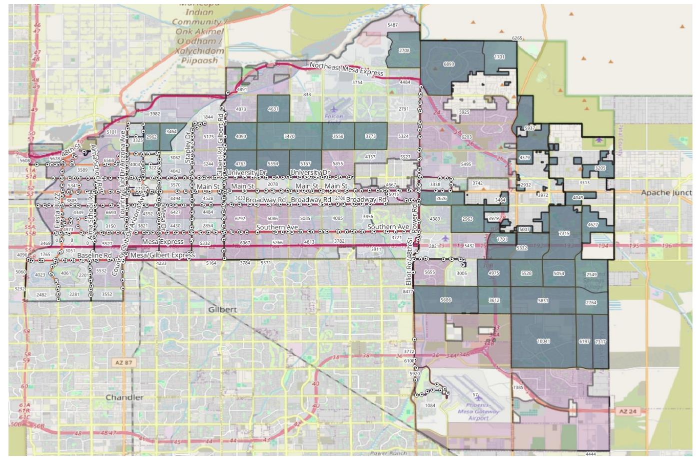

FIGURE 5. Census Tracts Without Existing Bus Routes

Identification of Underserved Areas To visualize transit service gaps, a spatial query was performed to select tracts with no intersection with existing routes. Figure 5 shows these regions, primarily concentrated in the northeast and southeast. These zones became the focal point for proposed route expansion.

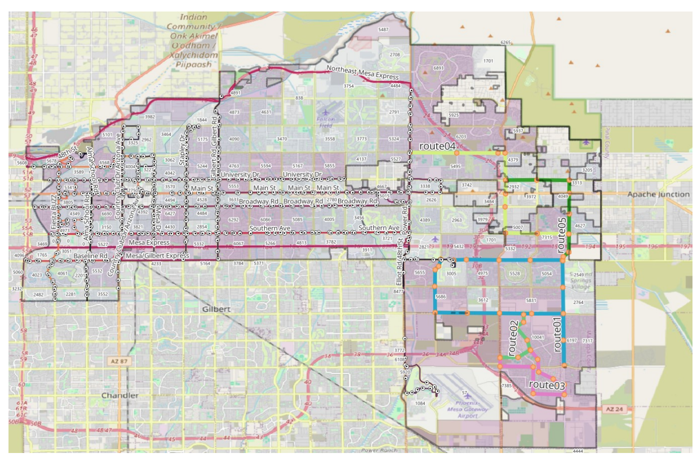

FIGURE 6. Newly Proposed Bus Routes and Stop Locations

Proposed Bus Routes and Stops Figure 6 displays five proposed bus corridors designed to serve the underserved census tracts. The routes were digitized using QGIS's manual line tools, following main roadways and high-density tracts. Potential bus stops were generated by extracting vertices from these new line features.

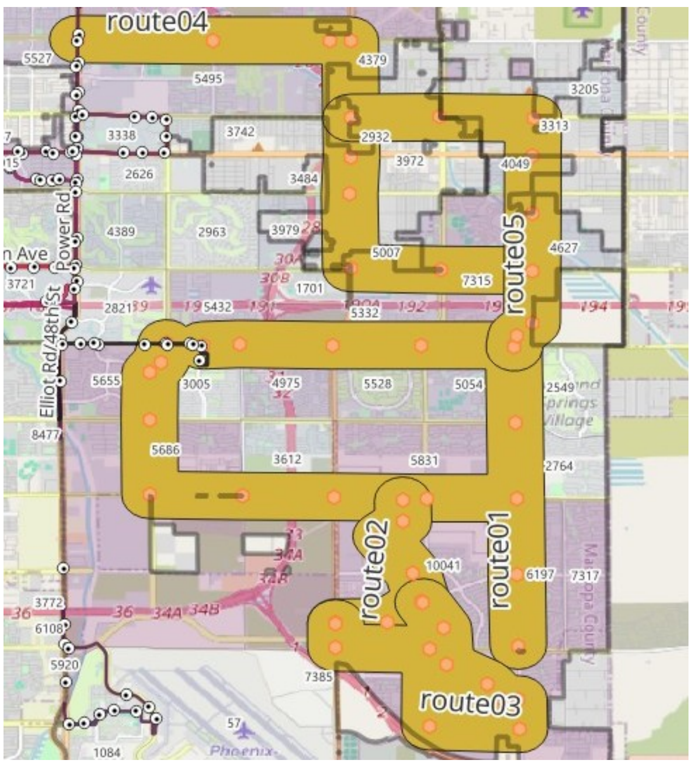

FIGURE 7. 500m Buffer Applied to Proposed Routes (Walkability Zone)

Buffering for Walkability Analysis To simulate realistic walking access, a 500-meter buffer was applied around the proposed bus lines. Figure 7 shows the spatial extent of areas that fall within a comfortable 5–7 minute walk of any new bus line. This walkability buffer was used to assess population accessibility.

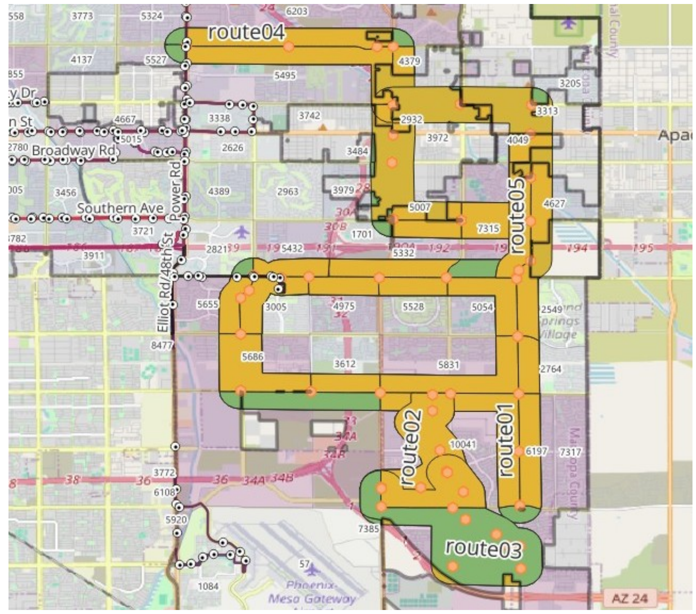

FIGURE 8. Overlay of 500m Buffer and Census Tracts Showing Area of Influence

Population Impacted by Proposed Routes Figure 8 shows the overlap of the buffer zones with Mesa census tracts. We calculated the proportion of each tract covered by the buffer using a new attribute, *overlap_ratio*. Only tracts with an overlap ratio of 0.2 or higher (i.e., at least 20% of the tract covered) were considered meaningfully served.

From this filtered set, we created a new population field, *pop_contributed*, by multiplying the tract population by the overlap ratio. The sum across all qualifying tracts was estimated to be approximately **63,414 residents** — representing the population likely to benefit directly from the proposed public transportation improvements.

Recommendations and Results

Financial Reallocation

One of the most immediate and actionable steps to improve public transit access in Mesa is the strategic reallocation of funding—particularly within Valley Metro's operational and capital budgets. Valley Metro's current fiscal year report outlines a total budget of approximately $158 million. However, of this amount, only $2.7 million is allocated to personnel and a mere $100,000 toward site improvements and maintenance—less than 2% of the total budget combined. This underinvestment is reflected in real-world outcomes: across Mesa and neighboring Tempe, a significant number of transit pass readers remain nonfunctional. Given the limited number of personnel available to perform onboard fare checks, this issue has led to widespread fare evasion, resulting in ongoing revenue loss.

Redirecting a larger share of funding toward repairs, maintenance, and hiring could not only help Valley Metro recover lost revenue but generate a return on investment through improved fare enforcement and a more reliable rider experience. In this case, better service translates to higher ridership, which in turn leads to increased fare revenue and long-term viability of the transit system.

Beyond operational improvements, capital investments are also necessary. Our proposed plan includes the addition of 45 new bus stops across underserved areas. Based on Valley Metro's internal estimates, the cost of constructing a standard micro shelter equipped with basic amenities is approximately $12,000. This brings the estimated construction cost of our proposal to $540,000 in total. To put this into perspective, Arizona's state-level budget allocated over $355 million in foreign aid to a single international initiative in 2023. Reallocating just 0.15% of that amount could fully fund this project—directly benefiting thousands of residents and improving accessibility for historically underserved communities.

There is also a broader budgetary context to consider. In the City of Phoenix, a disproportionately large share of the municipal budget is directed toward policing—an institution often scrutinized for over-policing and inequitable enforcement. A modest reallocation from such sources toward transit development in Mesa and the broader Valley Metro region could significantly elevate public welfare. In addition to increasing mobility, expanding transit infrastructure fosters job creation, reduces traffic congestion, and helps advance environmental equity—particularly valuable outcomes in times of economic uncertainty.

By adopting a more equitable and pragmatic budgeting framework, Valley Metro and its partner municipalities can unlock transformative improvements in public transit coverage and climate resilience—at a fraction of the cost of many current budget allocations.

Visualizing the Impact of Proposed Solutions

To assess the environmental benefits of our transit expansion, we constructed a series of emissions-saving scenarios using publicly available national averages. We assumed the following metrics :

1. Americans commute approximately 250 days per year.
2. Each round-trip commute is about 24.4 miles (12.2 miles each way), which we simplify to 12 miles one-way. We also added another distance value of 5 miles for more analytical comparisons
3. The average occupancy of a bus in the U.S. is about 10 riders per trip.
4. Diesel-powered buses emit roughly 2,680 grams of CO_2 per mile, whereas electric buses emit just 100 grams per mile.

Using these figures, we modeled uptake scenarios assuming that 5%, 10%, or 15% of the 63,414 people newly served by our proposed bus routes choose to commute via public transit. We also analyzed the outcomes for two trip lengths: 5 miles and 12 miles.

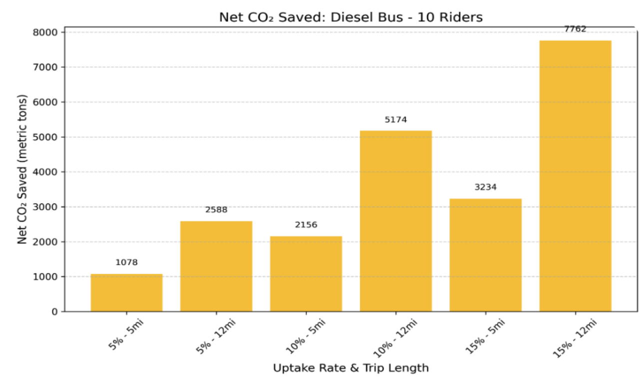

FIGURE 9. Net Annual CO_2 Saved with Diesel Buses (10 Riders per Trip)

Figure 9 displays the net CO_2 savings for diesel-powered buses servicing 10 riders. Even in the most conservative scenario—5% uptake and 12-mile commutes—the city could reduce carbon emissions by over 2,500 metric tonnes per year.

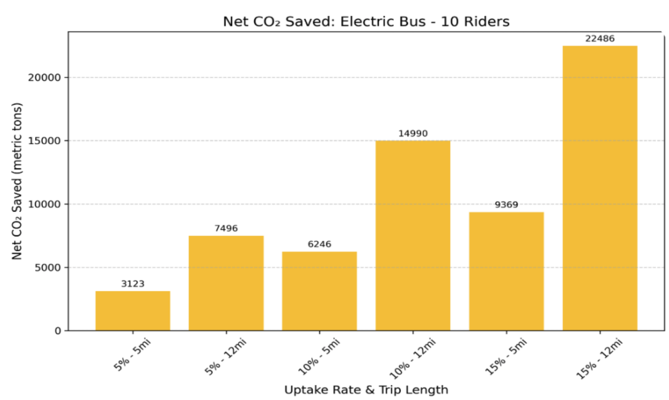

FIGURE 10. Net Annual CO_2 Saved with Electric Buses (10 Riders per Trip)

Figure 10 shows the same uptake scenarios assuming electric buses. The reduction in emissions more than doubles—surpassing 7,000 metric tonnes of CO_2 saved annually with just 5% uptake and longer commute lengths.

We also modeled scenarios assuming 20 riders per bus to explore higher-occupancy cases, presented below:

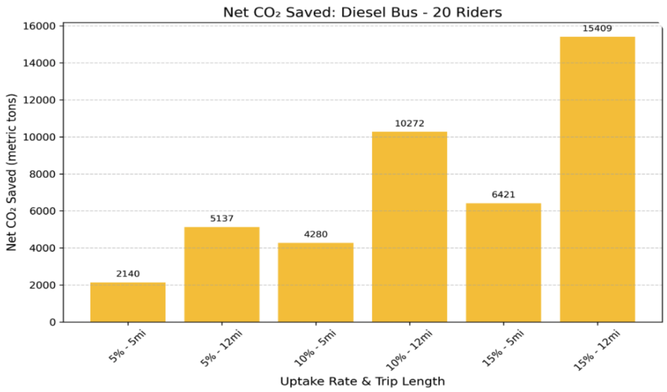

FIGURE 11. Net Annual CO_2 Saved with Diesel Buses (20 Riders per Trip)

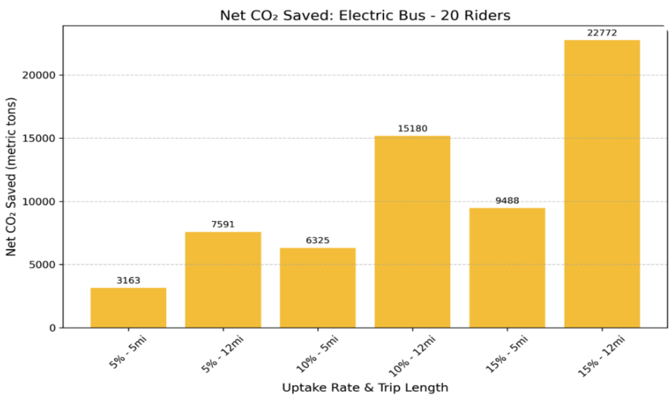

FIGURE 12. Net Annual CO_2 Saved with Electric Buses (20 Riders per Trip)

Averaging across all scenarios, we estimate a net savings of approximately 8,000 metric tonnes of CO_2 per year. To contextualize this number :

It's equivalent to planting over **400,000 trees** and letting them grow for a decade.

It's comparable to the emissions from **900,000 gallons of gasoline** burned.

It would offset the electricity used to power **800+ homes** for an entire year.

It's the same as eliminating over **20 million miles** driven by gas-powered cars.

This analysis quantifies the practical, climate-positive impact of investing in public transit—not just as a transportation alternative but as a measurable decarbonization strategy.

Conclusion

While achieving net-zero carbon emissions remains a critical long-term objective, this project underscores that localized, data-informed interventions—such as improving public transportation infrastructure—can offer immediate, measurable progress toward that goal. Public transit, when thoughtfully designed and equitably distributed, serves a dual purpose: reducing carbon output from private vehicles and expanding mobility access for underserved populations.

It is important to recognize that many current urban and economic models prioritize short-term returns, market efficiencies, and consumer convenience over long-term environmental sustainability. These priorities often result in structural barriers to climate action. However, informed, community-level planning can offer a pathway around these systemic challenges. Small-scale, realistic improvements—grounded in rigorous data analysis—can achieve more tangible outcomes than ambitious but unfunded or politically unviable strategies.

This project does not claim to offer a fully executable policy blueprint. Instead, it presents a multidisciplinary framework for exploring how cities like Mesa, Arizona can begin taking ownership of their environmental footprint. By integrating geospatial analysis, machine learning-based climate forecasting, and municipal financial review, we demonstrate the practical value of combining tools across disciplines to address complex sustainability challenges.

Ultimately, our hope is that this work contributes to a broader conversation—one where municipalities, transit authorities, and civic planners collaborate to make evidence-based, equity-centered investments in sustainable infrastructure. The climate crisis may be global, but the most effective solutions often start at the local scale.

Acknowledgements

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We are also grateful to the City of Mesa Open Data Portal, the U.S. Census Bureau, Valley Metro, and Open-Meteo for providing the publicly available datasets used in this analysis.

The tools used in this project include QGIS, Python, and LaTeX. This report would not have been possible without the open-source communities that maintain these technologies.

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