Fall 2021

Analyzing Alternative Modes of Transportation & Carbon Footprint in Gettysburg, Pennsylvania

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Abstract

As millions of students embark on their journey of college, many use different forms of transportation in and around their respective areas. The aim of this study incorporates the analysis of various forms of transportation, as well as each transportation method's marginal greenhouse gas emissions and marginal cost per mile in Gettysburg, Pennsylvania. Data was collected by testing each mode of transportation on a short trip to the local Walmart. The results show that the two modes of transportation that contributed the least to greenhouse gas emissions were biking and walking. The results for other modes of transportation that constitute the greatest greenhouse gas emissions were the car and rabbit transit (bus service). This study also identifies additional factors that have a positive (significant satisfaction), neutral (modest satisfaction), and negative (unsatisfactory) measurement regarding their overall experience with each transportation method. The research results indicate that biking was overall the best mode of transportation in Gettysburg, Pennsylvania with the e-scooter (electric scooter) having the second best mode of transportation. From an environmental standpoint, e-scooters pose greater risks than modes such as walking and biking because of user demographics and lifecycle emissions from production of e-scooters.

Keywords

transportation methods, carbon footprint

Disciplines

Environmental Studies | Sustainability | Transportation

Comments

Written for ES 400: Senior Seminar

Analyzing Alternative Modes of Transportation & Carbon Footprint in Gettysburg, Pennsylvania

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ES 400 Senior Seminar: The Automobile and its Effects on Culture and Environment

Environmental Studies

December 16, 2021

I. Abstract

As millions of students embark on their journey of college, many use different forms of transportation in and around their respective areas. The aim of this study incorporates the analysis of various forms of transportation, as well as each transportation method's marginal greenhouse gas emissions and marginal cost per mile in Gettysburg, Pennsylvania. Data was collected by testing each mode of transportation on a short trip to the local Walmart. The results show that the two modes of transportation that contributed the least to greenhouse gas emissions were biking and walking. The results for other modes of transportation that constitute the greatest greenhouse gas emissions were the car and rabbit transit (bus service). This study also identifies additional factors that have a positive (significant satisfaction), neutral (modest satisfaction), and negative (unsatisfactory) measurement regarding their overall experience with each transportation method. The research results indicate that biking was overall the best mode of transportation in Gettysburg, Pennsylvania with the e-scooter (electric scooter) having the second best mode of transportation. From an environmental standpoint, e-scooters pose greater risks than modes such as walking and biking because of user demographics and lifecycle emissions from production of e-scooters.

II. Introduction

The vastly popular use of the traditional internal combustion engine vehicles has caused traffic congestion, air pollution and habitat fragmentation which is why it is paramount that alternate modes of transportation are studied and utilized (Dalin & Rodriguez, 2021). While the transition to electric vehicles is soon on the horizon, action must be taken now to mitigate climate change impacts so that they may not be permanent according to a recent report from the Secretary-General of the United Nations Intergovernmental Panel on Climate Change (IPCC

2021). Options to achieve this goal include increasing ridership in public transportation, increased usage of walking and biking, and a decrease in private car ownership (Hollingsworth et al., 2019). In order to adapt these practices into reality, one must first have a complete understanding of the performance of each mode in relevant categories which this study seeks to provide.

Recent technological advances in alternative modes of transportation have produced innovative ways to get around, one being the rise in popularity of the e-scooter. E-scooters were first introduced to the US in September 2017 and in many cities their use exceeds that of bikes such Austin, Texas (Caspi et al., 2020). Different modes of transportation can potentially contribute to reducing private car use and mitigate its related externalities (congestion, emissions, noise, car accidents) (Christoforou et al., 2021). Walking and cycling for transport gain merits, as they are energy efficient and low pollutant, while also being the most affordable means of transport (Marquet & Miralles-Guasch, 2015).

Greenhouse gas emissions of cars and buses have been a problem for years now and are one of the main sources of GHG emissions, hindering the fight against climate change. Buses have proven to have 2691 g of CO2/L using diesel fuel, which is the main fuel used in public bus transit (Chan et al., 2013). This is similar to that of petrol cars. However, buses offer the option of car pooling which can significantly drop the GHG emissions per person compared to cars, in which this study seeks to identify the difference in GHG emissions of these two modes of transportation.

This is important to understand so that the public can select a mode of transportation that best serves their day-to-day needs in conjunction with reducing one's carbon footprint. It can be reasoned that, especially in a small town such as Gettysburg, most day-to-day commutes can be

done without the use of a car. This is important because an average vehicle emits about 4.6 metric tons of carbon dioxide per year while burning around 8,887 grams of CO2 per gallon of gasoline (EPA, 2021). Instead, this study from Arizona State and Ryerson University seeks to prove this theory and suggests that alternative transportation options may be able to increase transportation equity and reduce their transportation carbon footprint through accommodating e-scooters (Sanders et al., 2020). The rise of bike and e-scooters sharing companies can offer similar aspects to traditional options while saving money and carbon emissions and ultimately collectively contribute to the issue of Climate Change. Population density and proximity are key factors in evaluating the viability of alternate modes of transportation. A 2015 study found that densely populated urban areas utilize alternate modes of transportation at a higher rate than more rural areas due to accessibility and mobility (Marquet & Miralles-Guasch, 2015). This study aims to build off of the previous studies by combining background research and offering independent data and research as it pertains to our study area, Gettysburg, Pennsylvania. Gettysburg is a town located in Adams County in southern Pennsylvania and is home to the famous Battle of Gettysburg. Gettysburg is a rural town, however, the central downtown area is closely connected to the residential areas, offering opportunities for more short-distance and sustainable modes of transportation, but cars and trucks still dominate and as a result, traffic congestion is a constant problem. We argue that this study will give the residents of Gettysburg the wisdom to utilize alternate transportation more and thus solving Gettysburg's congestion issue.

The purpose of this study is to measure and analyze different transportation options to provide the general public with the information needed to assess one's transportation needs and environmental impacts so the consumer can make the most educated decision. This study will

quantify modes of transportation including an electric scooter, a car, a bicycle, a bus and walking and extrapolate data to understand the benefits and limits each pose in regards to carbon emissions, utility, speed, and cost. This study attempts to compare current modes of transportation available in the Gettysburg area while using the e-scooter as a potential alternative to save marginal CO2 emissions. Primary research suggests that bikes are the best choice of transportation for marginal CO2 emissions per trip and marginal cost per mile while still providing a competitive time (A-B) similar to that of the e-scooter but without added emissions of electrical use. We hope that the results of this study will convince the general public of the viability of alternate modes of transportation in Adams County, Pennsylvania. Few studies have been conducted on alternate transportation in this region and we hope this study initiates a movement of alternate transportation in rural areas to positively contribute to the fight against climate change.

Research Question #1: Which mode of transportation will be the most marginally carbon efficient?

Hypothesis #1: Due to the self-powering nature of a bike, we believe that the bike will have the lowest carbon emissions per mile while the bus will have the highest carbon emissions per mile.

Research Question #2: Which mode of transportation will get the user to his/her destination the fastest?

Hypothesis #2: Again, privately owned cars will provide the quickest trip over long distances, however, in local areas (towns and cities), the electric scooter would be a faster trip.

Research Question #3: Which mode of transportation will have the lowest marginal cost per/mile?

Hypothesis #3: Walking will have the lowest cost per/mile.

Research Question #4: Which mode of transportation will be the most overall efficient mode of transportation, being that a mode has the highest average of rating in each category?

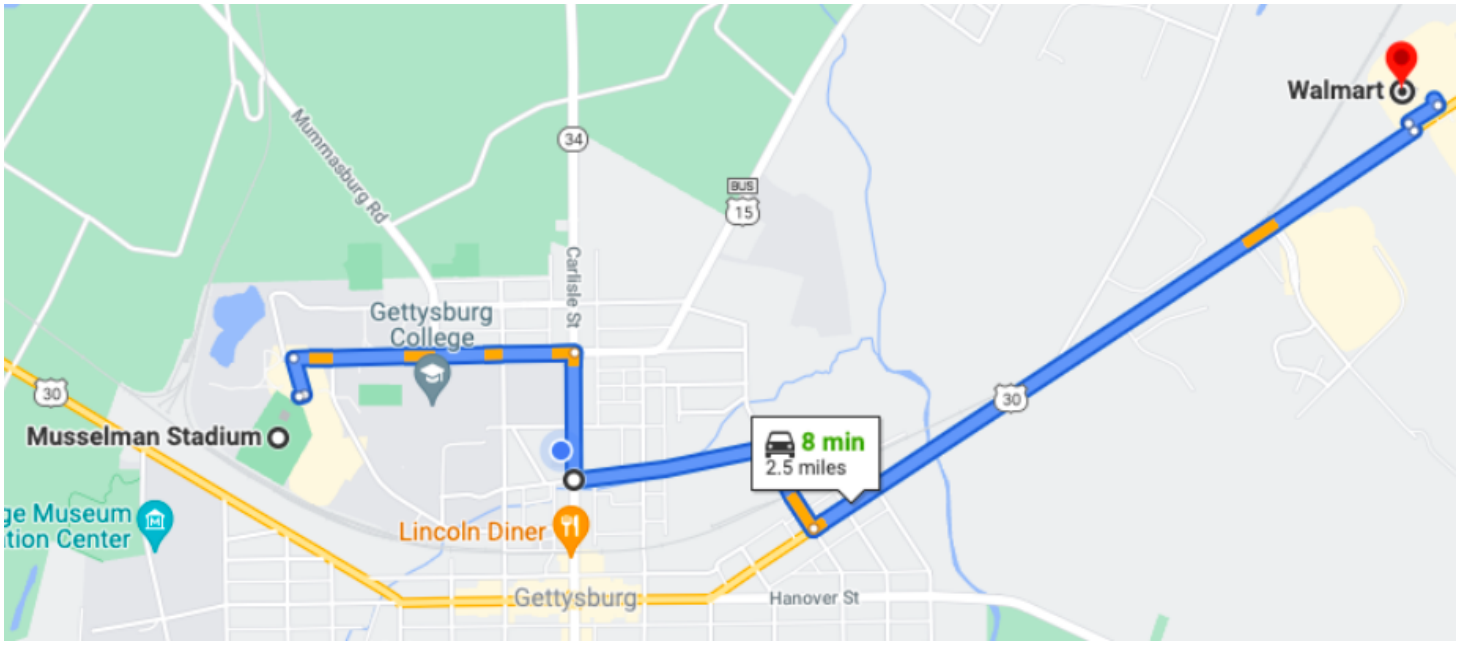
Hypothesis #4: The bike will overall be the best mode of transportation in Gettysburg, PA

In addition, we will make field observations about the utility, safety, and overall experience of each mode of transport mode

III. Methods and Research Design

Route for Data Collection:

Walmart:



Each mode of transportation will be tested on Monday, Tuesday, or Friday at 5pm to ensure consistent measurements throughout. The route is as follows: take a right onto W. Lincoln Ave from the Musselman Stadium parking lot. Then, continue onto W. Lincoln Ave. Next, take a right onto Carlisle Street. Then, take a left onto E. Water Street. Next, take a right onto N. East

Street. Finally, take a left onto Lincoln Highway and continue until you arrive at Walmart on the left. The e-scooter was tested on October 10, 2021 to October 16, 2021 and from October 22, 2021 to October 28, 2021. The car was tested on October 16, 2021 to October 21, 2021 and from November 4, 2021 to November 10, 2021. The bike was tested on October 22, 2021 to October 28, 2021 and from October 29, 2021 to November 4, 2021. The bus was tested on November 4, 2021 to November 11, 2021. Walking was tested on November 4, 2021 to November 11, 2021.

E-Scooters

To estimate the marginal GHG emissions associated with the e-scooter, the length and time of travel was measured. The specs of the scooter will be used with length and time of travel to get a measure of total kWh used on a given trip. The equation that will be used is $E = (Pt)/1000$, where E represents total energy in kWh, P represents power in Watts, and t represents time in hours. This measure of kWh will be used in conjunction with the average grams of CO_2/kWh of energy production in the United States, which is approximately 417.305 grams of CO_2/kWh.

Biking & Walking

The time and distance were measured.

Car

To get carbon emissions for a car, we will use Life360 to track the length and time of the trip. We will then calculate carbon emissions by using MPG rating for the vehicle and convert this measure into grams of CO_2. The equation of this section is, $E=MPG * L$, where E is total energy in kWh, MPG represents miles per gallon of the given vehicle and L for total length of the trip in miles. This equation will result in a measure of how much gas was used during a trip. This value will then be multiplied by the grams of CO_2 emitted from burning one gallon of

gasoline, approximately 8,887 grams of CO2/gallon to get our final measure of grams of CO2 (EPA, 2021).

Bus

To get carbon emissions for a bus, we will use Life360 to track the length and time of the trip. We will then calculate carbon emissions by using MPG rating for the vehicle and convert this measure into grams of CO2. The equation of this section is, E=MPG * L, where E is total energy in kWh, MPG represents miles per gallon of the given vehicle and L for total length of the trip in miles. This equation will result in a measure of how much gas was used during a trip. This value will then be multiplied by the grams of CO2 emitted from burning one gallon of diesel fuel, approximately 10,084 grams of CO2/gallon (EPA, 2021). We will then divide this number by the amount of people on the bus at a given time to get a total measure of grams of CO2 per person. In addition, we will calculate the total measure of grams of CO2 per person assuming a full bus (12 people).

Measure for Speed:

Time it takes to get to destination and back to Musselman Parking Lot (from point A to point B). One data point will be measured for the time it takes to get to Walmart from Musselman parking lot and the other will be from Walmart to Musselman parking lot.

Measure for Cost/mile:

Cost per mile of each mode of transportation (battery usage, gas usage, any cost associated with the mode of transportation).

Overall Measure of Efficiency:

Overall efficiency will be placed in a ranking system from 1 to 5 (1 being the best and 5 being the worst) for each mode of transportation. The average of the rankings for each mode will be found.

IV. Results

For the purpose of this section, transportation data for walking and rabbit transport were only tested twice. In addition, Tables 4-8 include all raw data for each transportation method. In the time section (Figure 2), the car took the shortest average trip to Walmart at just 7:53. For the bike, it took 13:56 and similarly, the e-scooter took an average time of 14:55 (Figure 2). In terms of walking and taking rabbit transit, walking took an average of 48:40 while rabbit transit took an average of 30:31 respectively (Figure 2). In terms of marginal CO2 emissions (Figure 3), both biking and walking had zero CO2 emissions. Rabbit transit had an average CO2 emissions of 1948.523 grams of CO2 while the car had an average of 888.7 grams of CO2. Comparably, if the bus were full (12 people) the amount of CO2 per person was 162.450 grams. The e-scooter had an average of 0.1245 grams of CO2.

Comparably, for the average cost per mile (Figure 4), walking and biking were zero. Additionally, rabbit transit also had a zero cost per mile. When it comes to the e-scooter and car, the e-scooter had an average cost per mile of 0.0131 cents while the car had an average of 0.357 cents. For qualitative measurements (Figure 5, Table 3), the car had the highest rating of 4.375 while walking had the lowest rating of 1.5. When it comes to the bike, e-scooter, and rabbit transit, the bike got a rating of 3.125, the e-scooter got a rating of 2.625, and rabbit transit got a rating of 2.5 respectively.

V. Discussion

The bike was found to be the best overall mode of transportation for its affordability and carbon efficiency, but lacked in other measurements. Qualitative measures suffer in comparison to that of a private car with the highest value for qualitative measures as well as time (A-B), making it clear the main reasons cars are used at a higher rate than any other mode of transportation (Figure 5, Table 3). Walking and using the Rabbit Transit system ranked the lowest among all categories due to the time of the trip and subsequent qualitative measures. Overall, the bus generates the most marginal CO2 emissions due to the lack of ridership resulting in a higher measure of CO2 emissions per person but ranks second best if the bus were to be full (12 people). Bus transportation is a viable option to reduce marginal CO2 emissions in densely populated urban areas with high ridership as seen in a recent study (Chan et al., 2013). However, given the rural nature of the Gettysburg area, bus travel is not a viable mode of transportation in this study unless more people were present.

Bicycles have long been a preferred alternate mode of transportation for centuries and are still heavily utilized today. However, a general obstacle for widespread bike use in many areas is the infrastructure in place to ensure safety for bikers (Lowe, 1990). Municipalities have begun to promote biking as a critical transportation alternative in this movement away from privately owned cars due to congestion relief and environmental and public health benefits (Schonor & Levinson, 2014). Between 1999 and 2011, the federal government has provided over $7 billion in funding for pedestrian and bicycling infrastructure (Federal Highway Administration 2012). First hand experience provides insight on this issue comparing the infrastructure of Gettysburg, Pennsylvania and Boulder, Colorado. Cycling is much more popular in Boulder due to the

environmental beliefs of many of the population, but also the incredible biking infrastructure present around the city with wide biking lanes separate from both roads and sidewalks with plenty of bike parking. Comparatively, Gettysburg has rather narrow and bumpy sidewalks that do not make one feel particularly safe when traveling at high speeds (Appendix for reference pictures). It is important to implement this infrastructure as bicycling provides the least CO2 emissions out of any other option and is relatively quick from point A to point B. From a ride-sharing perspective, bikes are a much more cost effective and efficient mode of transportation to be implemented at Gettysburg College, which was conveyed to the Student Senate. However, in many places e-scooter sharing platforms are used much more than that of bicycles (Caspi et al., 2020).

The COVID-19 pandemic had a major impact on the transportation sector, most notably public transportation such as buses, and may have contributed to the low ridership measured in this study. Due to the highly contagious nature of the virus, and federal social distancing regulations, many chose to purchase a private car instead of utilizing public transportation even in urban areas resulting in increased CO2 emissions (Tirachini & Cats, 2020). Buses can be an efficient and sustainable form of transportation if ridership keeps the bus relatively full constantly as to reduce CO2 emissions per person (Kumar & Ganguly, 2018). Spatial analysis shows that buses are generally effective in this sense in urban areas where density populated areas result in high ridership (Tirachini & Cats, 2020). At reasonable occupancy rates, public transport uses space and energy many times more efficiently than cars, and creates much less pollution (Lowe, 1990). However, as seen in our study, ridership is not high enough to make buses a sustainable mode of transportation in the Gettysburg area whether that be due to COVID-19 or simply low popularity. Low popularity is a concrete possibility as data collection

along this route was anything but enjoyable with bumpy rides, rude bus drivers, and long route times.

Walking was found to be the most carbon efficient but the lowest in qualitative measures due in part to the rural nature of Gettysburg. The idea of the walkable city presents environmental, public health and wellness, social, and economic benefits as seen in Barcelona's super blocks (Marquet & Miralles-Guasch, 2015). These blocks consist of 9 regular city blocks where cars are not allowed to travel and the streets are used as a public space for local vendors and farmer's markets. Also, the slower rate of passage from these store-fronts results in more consumer interaction and a boost for local businesses. Unfortunately, this model can only really be applied to urban areas which excludes Gettysburg from adopting this infrastructure. As seen in the data collection, walking takes a considerably longer time to get to one's destination and is not enjoyable given the spaced out nature of Gettysburg making it an extremely inefficient mode of transportation.

The car was found to have the best measurements for speed and qualitative measures and is why it has long been the preferred method of transportation both nation and world wide, resulting in huge amounts of CO2 emissions since its inception in the 1800s. Recently, transportation has become the sector with the highest CO2 emissions, surpassing that of power plants. The federal government has long tried to use fuel economy standards to control these emissions, but loopholes in the CAFE standards have led to disproportionate usage of large vehicles with low fuel economy making our problem worse. With G.M. recently accounting their initiative to become fully electric by 2035, other corporations have followed suit showing that the transition to EVs can only be driven by corporate interests rather than government action. This study has shown that cars are indeed the fastest and most comfortable mode of

transportation, but it is important to consider the underlying CO2 emissions of this mode and one should seek to find a more sustainable car, or find an alternate mode.

A main limitation of this study was the absence of a measure of life cycle emissions. The e-scooter is marketed as a new sustainable mode of transportation when in reality, they contribute to increased CO2 emissions. This is because the mainly younger demographic of users would have otherwise used a bike or simply walked had they not have had access to an electric scooter (Christoforou et al., 2021). As a result, manufacturing emissions and subsequent usage emissions do not take carbon out of the atmosphere because it is not reducing the usage of private cars, which are the main emitters of GHG. Recent studies suggest that electric scooters are not used for commuting purposes, but rather for leisure and other activities, while bike-sharing platforms have been found to be used as a commuting mode of transportation (Caspi et al., 2020). When asked by Gettysburg College Student Senate about a ride-sharing platform for electric scooters, this study argued that an implementation of electric scooters would be both costly and inefficient, as well as counter productive to the college's initiative to become carbon neutral by 2030. This is because research suggests that a fleet of cars and staff are required to maintain, supervise, and collect e-scooters and bring them back to the charging station, which results in CO2 emissions greater than that of the scooter itself (Sanders et al., 2020). Had this study included lifecycles emissions, walking would be the only mode without up front carbon emissions. Cars produce around 12 tons of CO2 in the mining, transportation, manufacturing, and assembly of a typical SUV such as the Toyota RAV4 (Gold et al., 2021). Buses have an even higher carbon cost of manufacturing while the bike has a very low cost of production at only 5 grams of CO2 (Leuenberger, Frischknecht, 2010).

A few more limiting factors must be noted. This study was conducted in the fall months resulting in lower temperatures on average towards the latter half of the data collection period. This directly hinders the qualitative measures for options such as the scooter or bike due to the outdoor nature of these modes of transportation and was noted on multiple occasions in the notes for each trial. As was touched on in Gettysburg College Student Senate's Committee on College Life and Activities, the temporal barrier to year-round use is a main hurdle for implementation as a ride-sharing program on campus. Another limiting factor of the study was the inability to account for CO2 emissions of walking and biking in food production and transportation. At the onset of our study, we sought to calculate these measures to provide the truest account of carbon footprint for these modes of transportation. This would be an important topic for future study as the average global diet accounts for CO2 emissions and is estimated that walking and cycling an additional kilometer may result in GHG emissions up to 0.26 kgCO2e/km and 0.14 kgCO2e/km respectively (Mizdrak et al., 2020). Due to time constraints of this study only being a semester long, it would have been greatly challenging to incorporate this aspect into the study. Food production can be attributed for large amounts of CO2 emissions which could have offset the findings of this study (Kroyer, 1995). More specifically, one's diet can also have a substantial impact on carbon emissions and would be interesting to see how Gettysburg College's menu choices in Bullet and Servo can help the college come closer to becoming carbon neutral by 2030 (Weber & Matthews, 2008). We hope that future studies on this topic take into account food production and transportation related to calories burned on a bike or walking as well as menu choices.

Based on our results, we have a few suggestions for the Boro of Gettysburg and Adams County, Gettysburg College, and topics for future study. We have previously discussed the

limitations that exist with biking in Gettysburg, most notably, the current infrastructure in place for pedestrians and bicyclists alike. Throughout the data collection process, we felt unsafe riding on the shoulder of a major road without any buffer or bike lane. We would suggest that the Boro of Gettysburg should allocate substantive funding for more smooth sidewalks with buffers, wider shoulders, and the implementation of bike lanes to promote local alternative transportation. As was discussed in our presentation with Gettysburg College's Student Senate, our results indicate that bikes would be a better option for an on-campus ride-sharing platform than the electric scooter due to its higher carbon efficiency and lower overhead and operating costs. Lastly, we urge future researchers to attempt this study considering lifecycle emissions for all modes of transportation. Furthermore, we hope that future studies will quantify the real carbon footprint of biking and walking by measuring calories burned and deriving the related carbon emissions from food production and transportation to get the fullest scope of carbon footprint of transportation.

VI. References

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VII. Tables, Figures

Figure 1. Study area.

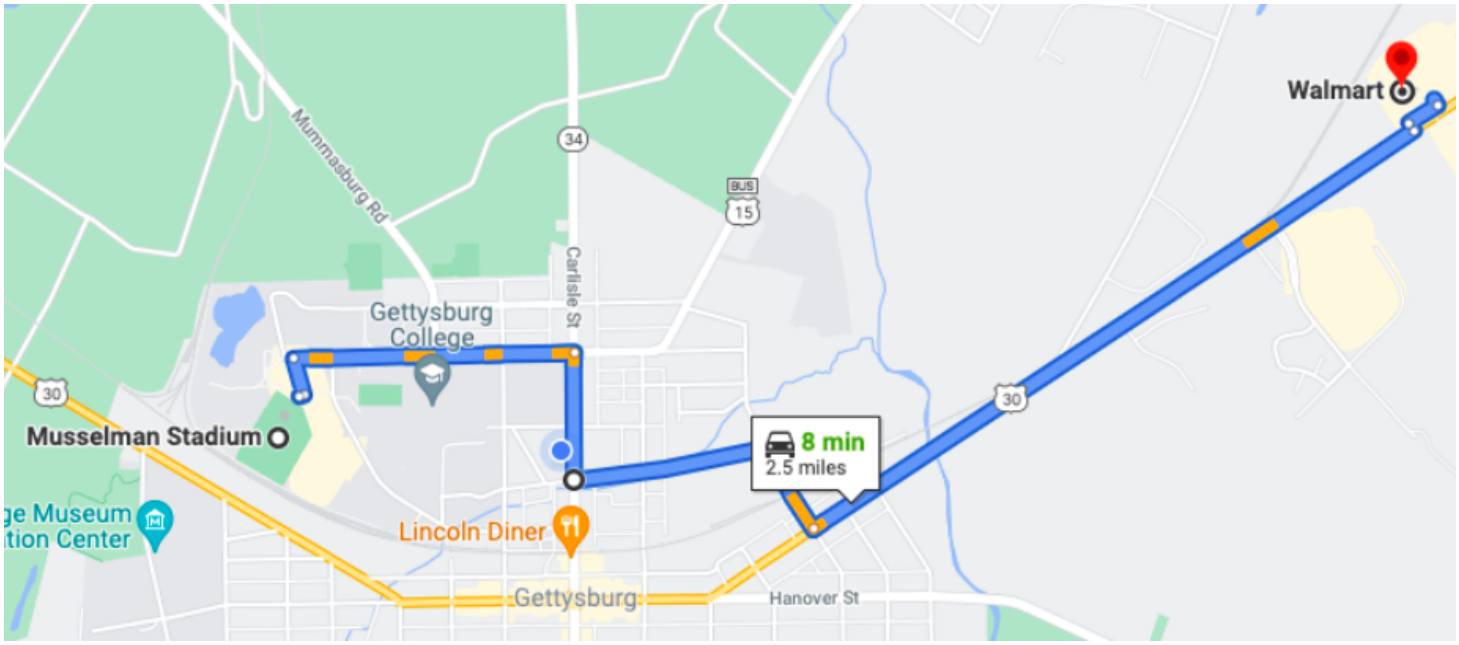

Figure 2. Time it took each mode of transportation to travel to Walmart in Gettysburg, Pennsylvania.

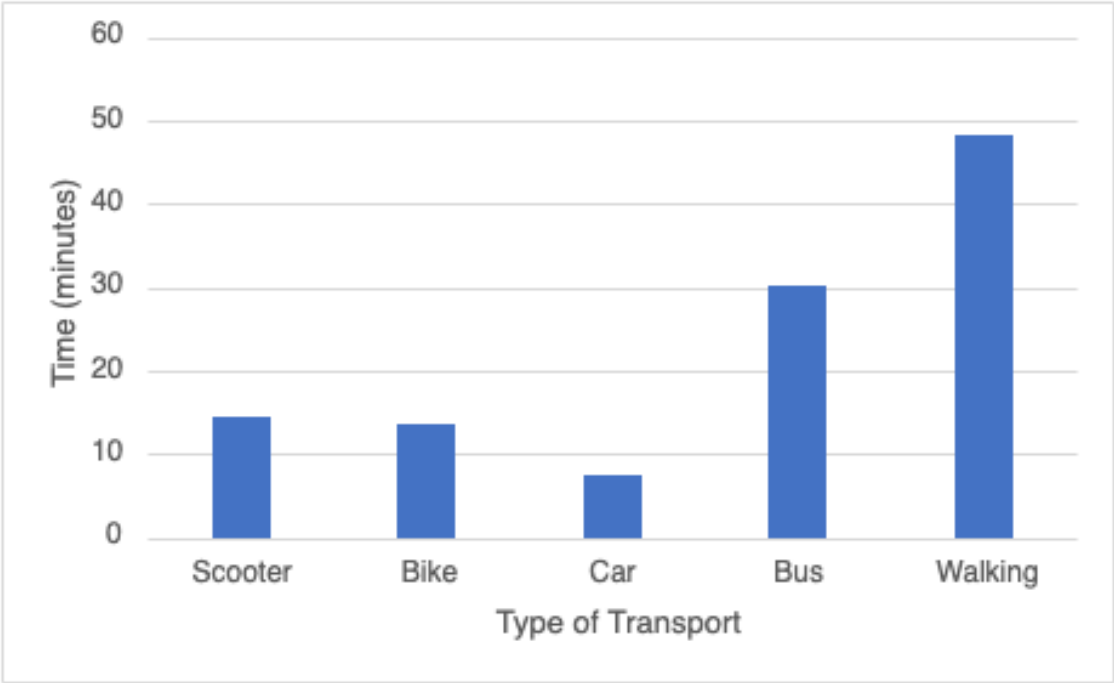

Figure 3. CO2 emissions for each mode of transportation traveling to Walmart in Gettysburg, Pennsylvania.

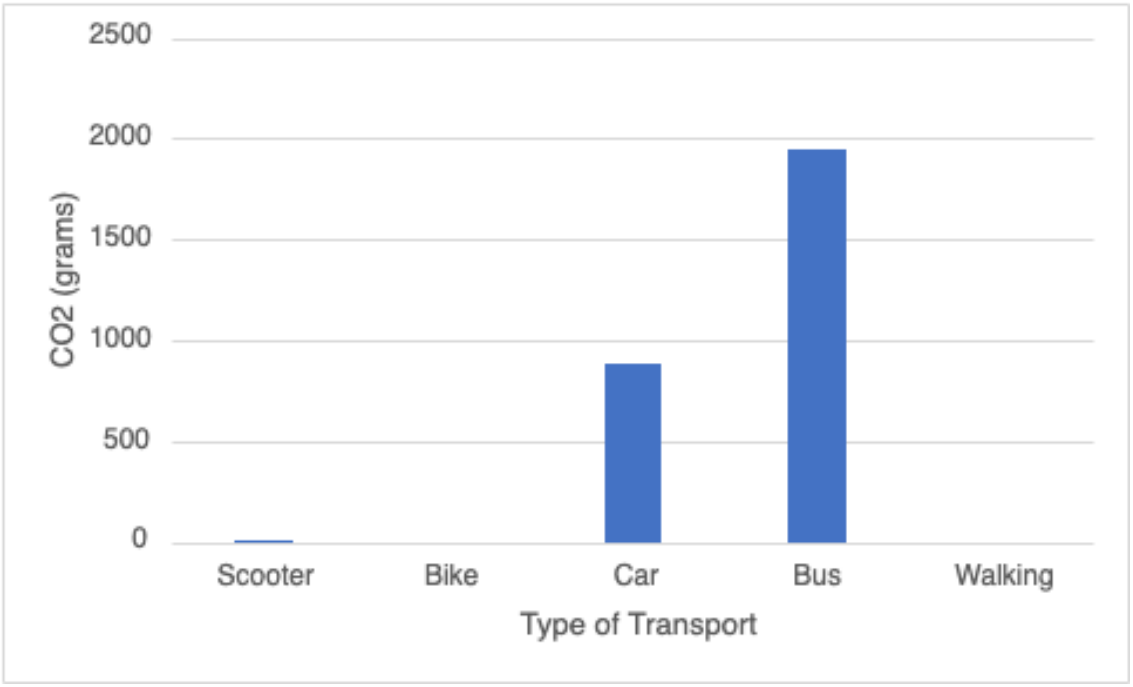

Figure 4. Cost per mile for each mode of transportation traveling to Walmart in Gettysburg, Pennsylvania.

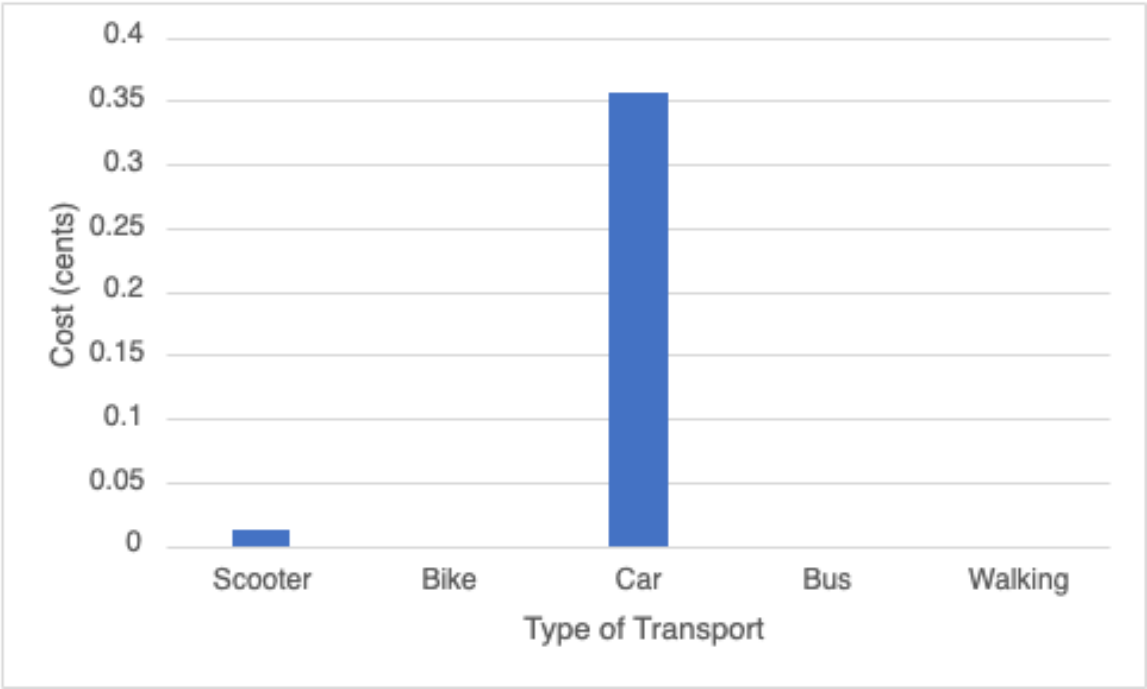

Figure 5. Qualitative measurements for each type of transportation method traveling to Walmart in Gettysburg, Pennsylvania.

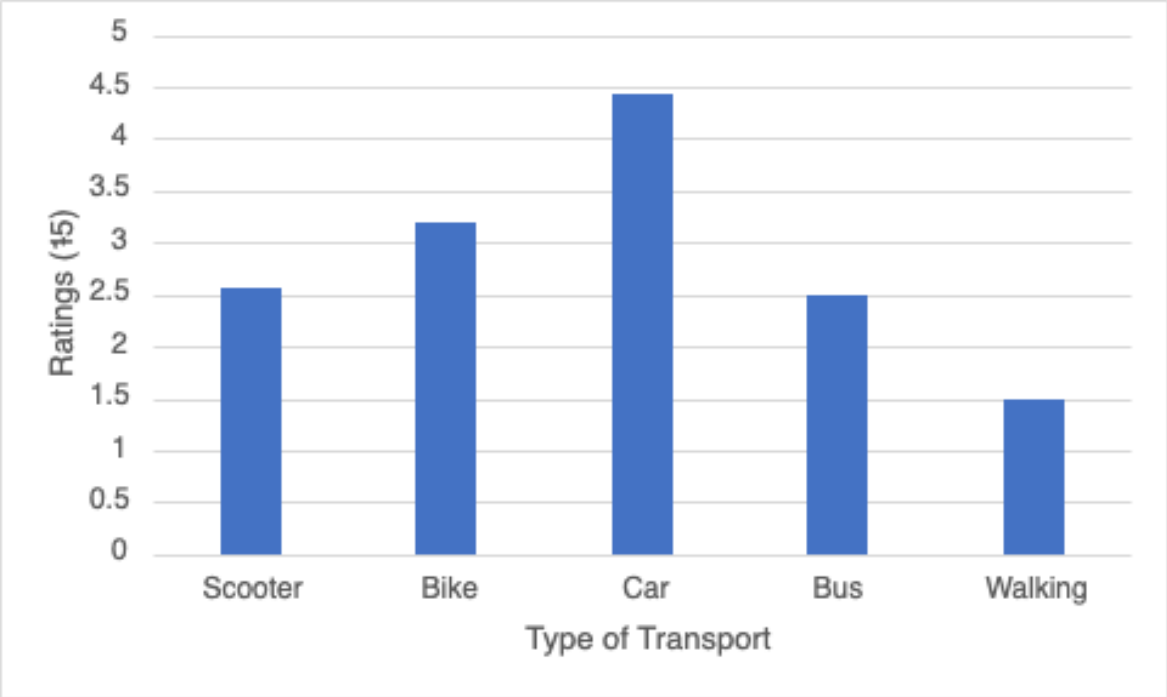

Table 1. Averages of data from all modes of transportation.

Trial	E-Scooter	Bike	Car	Bus	Walking
Time (A-B)	14:55	13:56	7:53	30:31	48:40
CO2 Emissions	0.125	0	888.7	1948.523	0
Cost Per Mile	0.013	0	0.357	0	0
Qualitative Measurements	2.563	2.188	4.438	2.500	1.500

Table 2. Data collection of each transportation method including time and date of each mode tested.

	E-Scooter	Car	Bike	Rabbit Transit	Walking
Number of Trips	7	8	8	2	2
Time of Day	5pm	5pm	5pm	5pm	5pm
Day of the Week	Monday, Tuesday, Friday	Monday, Tuesday, Friday	Monday, Tuesday, Friday	Tuesday, Friday	Monday, Friday
Dates of each Trial	10/10/21-10/16-21, 10/22/21-10/28/21	10/16-21-10/21/21, 11/4/21-11/10/21	10/22/21-10/28/21, 10/29/21-11/4/21	11/4/21-11/10/21	11/4/21-11/10/21

Table 3. Qualitative measurements for each mode of transportation (ranked 1-5).

Trial	E-scooter	Car	Bike	Rabbit Transit	Walking
1	2	5	5	2	1
2	5	5	5	3	2
3	4	5	1	-	-
4	3	5	1	-	-
5	2	3	2	-	-
6	1	4	2	-	-
7	2	3	4	-	-
8	2	5	5	-	-
Averages	2.625	4.375	3.125	2.5	1.5

VIII. Appendices

Table 4. Data collected from e-scooter (electric scooter).

Trials	Time (A-B)	Distance of Trip	Gram of CO2	Cost Per Mile
1	-	-	-	-
2	14.56	2.5	0.124	0.0123
3	15.07	2.5	0.128	0.0135
4	14.47	2.5	0.123	0.0130
5	14.32	2.5	0.122	0.0128
6	14.53	2.5	0.124	0.0130
7	15.05	2.5	0.128	0.0134
8	14.41	2.5	0.123	0.0129

Table 5. Data collected from car.

Trials	Time (A-B)	Distance of Trip	Gram of CO2	Cost Per Mile
1	7:34	2.5	888.7	0.357
2	8.47	2.5	888.7	0.357
3	7:19	2.5	888.7	0.357
4	7:51	2.5	888.7	0.357
5	6:59	2.5	888.7	0.357
6	7:14	2.5	888.7	0.357
7	8:02	2.5	888.7	0.357
8	7:15	2.5	888.7	0.357

Table 6. Data collected from biking.

Trials	Time (A-B)	Distance of Trip	Gram of CO2	Cost Per Mile
1	12:24	2.5	0	0

2	13:12	2.5	0	0
3	15:47	2.5	0	0
4	13:37	2.5	0	0
5	14:04	2.5	0	0
6	13:05	2.5	0	0
7	12:56	2.5	0	0
8	14:13	2.5	0	0

Table 7. Data collected from walking.

Trials	Time (A-B)	Distance of Trip	Grams of CO2	Cost Per Mile
1	48:34	2.5	0	0
2	48:15	2.5	0	0

Table 8. Data collected from rabbit transit.

Trials	Time (A-B)	Distance of Trip	Number of People	Grams of CO2/Person	Cost Per Mile
1	33:46	5.3	3	2226.88	0
2	26:52	5.3	4	1670.16	0

Honor Code: *I affirm that I will uphold the highest principles of honesty and integrity in all my endeavors at Gettysburg College and foster an atmosphere of mutual respect within and beyond the classroom.*

Paul Krakoviak & Sean Gallagher