1 Executive Summary

Considering the growing threat to the global climate, consumers, companies and governments are all searching for sustainable solutions to these impending problems. At 30 % of all greenhouse gas emissions, the transportation sector is both the largest and the fastest growing source of emissions in the United States [1]. With freight covering 23 % of these emissions, any change in the greenhouse gas emissions due to freight has the potential to make a large environmental impact [2].

One recent development that has the potential to revolutionize this industry is the replacement of traditional diesel semi trucks with electric semi trucks. These electric trucks offer many of the same benefits of electric cars, but since the market for these trucks involves large companies rather than individual consumers, they have the potential to make a larger impact at a relatively quickly pace. With plans for Tesla, Freightliner, and other major companies to roll out the first electric semi trucks in the next couple years, these alternatives to diesel trucks are quickly becoming a reality [3][4].

Electric semi trucks present not only environmental solutions, but also economic benefits. Despite their higher initial investment and likely lower lifetime, electric semi trucks can provide a positive return on investment (ROI) as early as 5 or 6 years after their purchase [5]. The significantly lower fuel and maintenance costs of electric semis when compared to traditional diesel trucks provide a significant economic benefit in the long term.

While creating our model for "Shape up or ship out," we calculated the replacement rate of traditional semi trucks and multiplied it by the probability of substituting an electric semi for its diesel counterpart. In order to improve the accuracy of our model, we used a recursive function that predicted the percentage of trucks that will be electric based on the previous year.

For "In it for the long haul," we took into account two factors: the length and business of the route in question. The length corresponded to the number of charge stations and the business to the number of outlets at each charge station. The numbers calculated reflect the predicted minimum number of charge stations and outlets that were needed to accommodate electric truck traffic.

In "I like to move it, move it," we focused on the environmental impacts of electrification of trucks more than any other factor. The model estimated the CO_2 emissions for diesel trucks and electric trucks. We found that electric vehicles cut CO_2 emissions by more than half across all trips.

These models helped us to make sense of the way electric energy will fit into our society. As time progresses, technology does too, and there is no denying that. Electrification of trucks is just one of many ways that environmentalism has become one with technology, rather than its enemy. By 2040, electric trucks will be on the rise – comprising 8.6 % of the total truck population, according to our model in section 2. Although adapting to this change will be expensive, building electronic infrastructure won't cost more than is reasonable, as spending to build a new highway or repave the roads would be substantially more, as shown in the conclusion of section 3. Finally, section 4 shows that electric really do make a difference in the energy consumption of trucks.

Contents

2 Shape Up or Ship Out

2.1 Restatement of Problem and Introduction

The upcoming introduction of electric trucks into the market in 2020, such as the Tesla semi, has provided truckers and fleet managers with the option to switch to electric vehicles over the traditional diesel ones. We can estimate the percent of trucks that are electric as a function of years past their initial release.

We simplified our problem by choosing and analyzing certain factors that impact electric truck use, and predicted how each of these factors will change over the next twenty years.

To address the problem, we will start by taking into account the replacement of standard semi trucks. Then we will consider the probability that each of these semi trucks will be replaced by an electric truck rather than a diesel one. This probability can be modeled by analyzing the combined economic factors of electric cars and the environmental pressure to switch to these cars.

2.2 Assumptions and Simplifications

1. **Assumption:** We will assume that the infrastructure is adequate to support the shift to electric trucks. Consequently, deterrents related to lack of infrastructure, such as range anxiety [6], can be dismissed.
   Justification: The assumption is declared in the problem statement.

2. **Assumption:** Tare weight of the vehicles will contribute a negligible amount to the changing use of electric vehicles.
   Justification: Out of the 80,000 pound total weight limit, an electric truck's extra weight contributes to only 4,000 of those pounds. Therefore, the tare weight does not have a profound impact on our model [7].

3. **Assumption:** Semi trucks will not be replaced until they reach the end of their lifetime.
   Justification: This assumption is reasonable due to the high initial investment required for new trucks whether they are powered by diesel or electric. Since this cost is very high relative to maintenance and fuel costs, it is not economically advantageous for truck companies to replace trucks before they reach the end of their useful lifetime.

4. **Assumption:** There are no electric semi trucks currently in use, but they will be in production this year.
   Justification: The majority of electric semi trucks will be coming out in 2020 or 2021; currently, the manufacturers who have come out with electric semis comprise less than 1 % of all trucks in use [8].

5. **Assumption:** Once a truck has been switched to electric energy, it will not be switched back to diesel.
   Justification: Switching back to diesel from an electric model would only be cheaper in the initial purchase costs - not the long run. We can, thus, safely assume that once a company has switched a truck to electric, it will stay that way, for not only economic savings but also pressure to be more environmentally friendly as well. This assumption also helps to simplify our model significantly.

6. **Assumption:** We can assume that the number of semi trucks in demand will stay approximately constant.
   Justification: The production of semi trucks has fluctuated in the past, but apart from temporary drops during recessions, no significant lasting increase or decrease in demand can be seen [9].

7. **Assumption:** Technological innovation will remain relatively stagnant in the next 20 years, meaning the cost of parts for electric vehicles will also remain level.
   Justification: This assumption saves a significant amount of time and simplifies the model.

2.3 Developing the Model

Let $U(t)$ equal the proportion of semi trucks that run on electric power t years after 2020. We will consider replacement rates, environmental pressure from consumers and economic advantages to calculate $U(t)$.

Replacement of Standard Semi Trucks All semi trucks, whether diesel or electric, wear out, giving them a limited lifetime. Traditional diesel trucks have an average lifetime of 16 years [14]. Using this figure, we can model the proportion of replaced trucks with either type of new truck, $R(t)$ as a function of time in years after 2020, t, using the following function:

$$R(t) = \frac{1}{16}(1 - U(t-1))$$

This function reveals that even if all other factors favor electric semi trucks, it will still take 16 years before all diesel trucks are replaced by their electric counterparts, therefore the proportion of electric semi trucks in the operational fleet is expected to remain below $R(t)$ at all times. This is stated in Assumption 3.

Consumer Environmental Pressure Companies have been known to take consumer demand into account. Consumers who show interest in environmentalism will be drawn to companies that can support their ideals. In an effort to attract these consumers and maintain their reputations by the general public, electric trucks may seem to be more favorable options than diesel trucks.

In an effort to quantify consumer views on the issue of sustainability, specifically as it pertains to electric vehicles, Google Trends was used to analyze searches that contained the words "electric cars" and searches under the topic of sustainability [20]. These two results were added together and analyzed with a sinusoidal regression. A sinusoidal regression is appropriate because media coverage and public opinion comes and goes in cycles.

The regression equation can then be scaled within the range from 0 to 1 to model the extent with which environmental considerations from consumers affect companies' choices for whether to switch to electric semi trucks. Recognizing that this is just one of many factors that companies consider, the regression equation can be multiplied by a factor of 0.15.

$$\omega(t) = 0.15\left(1 + \sin\left(4.14 \times 10^{-6}t + 671\right)\right)$$

Economic Factors Companies are generally also influenced by the economic factors that go into their transportation. Electric cars can both cost more and save companies money, depending on the specific factor in question.

Economic Factor	Net Cost Increase
Purchase Cost	\$30,000-\$60,000
Fuel Cost	-\$200,000
Cost per Mile	-\$0.25

Figure 1: The net cost of each economic factor, shown in the price the owner would have to pay. If a price is negative, that represents a saving [10] [19].

The return on investment (ROI) for electric semis is defined as the number of years to make a profit after buying a car. It is also dependent on the length of travel by the truck. Long-haul vehicles, for example, are estimated have to wait around 6.6 years to make back the money, compared to the 5 years for their short-haul counterparts [5]. This difference can be modeled by the equation $L = 1.32 \times S$, where L is the ROI for long-haul and S is the ROI for short-haul trucks. In other words, short-haul vehicle owners can be estimated to be 1.32 times more likely to switch to electric vehicles due to their faster ROI.

It can also be stated that short-haul trucks make up roughly 5 % of the total truck population [11]. Therefore, the model can assume that 5 % of trucks being deposed are 1.32 times more likely to be replaced with electric trucks.

$$P(t) = (\omega(t) \times 1.32 \times 0.05) + (\omega(t) \times 0.5 \times 0.95)$$

Where $P(t)$ represents the proportion of trucks replaced with electric ones out of the trucks that are replaced.

Final Model All of these factors can be brought together into one final model by multiplying economic and consumer pressures by the replacement function, $R(t)$. Multiplication is the appropriate way to combine the factors because each of the factors have a positive relationship on the proportion of semi trucks that are electric. If we allow U(t) to be the percentage of electric semis over time, then we get the following equation:

$$U(t) = U(t-1) + (P(t) \times R(t))$$

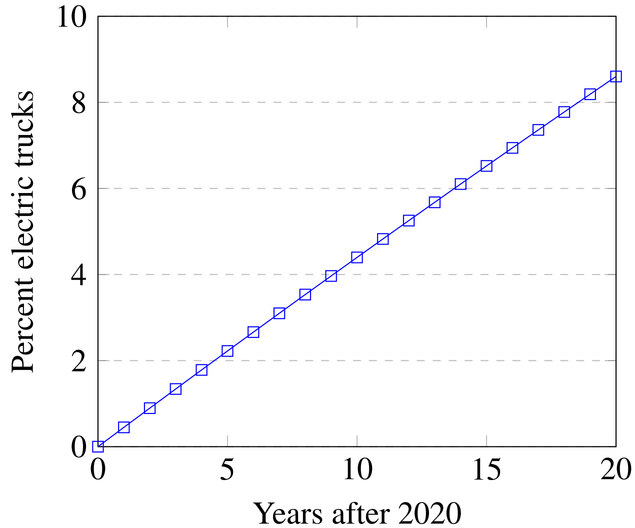

Figure 2: The percent of trucks that will be electric semis after 2020.

2.4 Applying the Model

Predicting the Future To calculate the the percent of electric vehicles that are semis at $t = 5$, 10, and 20, we can plug in these times to our equation $U(t)$.

t (years after 2020)	$U(t)$ (Percent of semi trucks that are electric)
5	2.2 %
10	4.4 %
20	8.6 %

Figure 3: The results of our model, $U(t)$, when plugging in t years after 2020.

2.5 Discussion and Conclusion

The Importance of Incentives Our model predicts that in 20 years, only 8.6 % of trucks will have been electrified. Despite the number one barrier being removed to the electrification of trucks–infrastructure [6]–companies still failed to produce significant changes to their overall energy consumption. Of course, any change in the right direction is good, but with the current rate of climate change and resource depletion, faster change is crucial. Passive incentives, like creation of infrastructure, are not enough to help encourage the transition to electric vehicles. Instead, active incentives, like tax breaks and rebates, should be prioritized. These incentives, often provided by the government, may help to raise the proportion of electric vehicles significantly, thus helping the truckers and the Earth in the long run.

Reflecting on the Model The model shows that in 20 years, 8.6 % of trucks will be electric. Although small, this does mean there will be an increase in electric truck usage from the current usage. This is in line with the fact that electric vehicles do provide a net positive effect on their owners. Although they do cost up to $60,000 more, electric cars have a relatively fast ROI, considering how much money is saved on factors such as fuel and repairs [5]. Once 20 years have passed, therefore, it is reasonable to assume the percentage of trucks that have been electrified has increased.

3 In it for the Long Haul

3.1 Restatement of Problem and Introduction

In relation to the rising demand for green energy, the manufacturing of electric trucks has seen significant developments in recent years. In order to sustain a completely electric fleet of semi trucks, an extensive network of charging stations must be installed and maintained on major truck routes for easy and reliable access for recharging.

3.2 Assumptions and Simplifications

1. **Assumption:** We will assume that all charging stations considered in this problem will be used exclusively for single driver long-haul electric semi trucks, and that the amount of electric traffic supported will be the equal to the total single driver long-haul present today.

   Justification: By considering only the traffic that the problem statement mentions, the research for the model will be simpler. Also, this model could be easily extended to incorporate regional-haul trucks.

2. **Assumption:** We will assume that all trucks will charge from 20 % to 80 % capacity.

   Justification: It is recommended charging electric vehicles from 20 % to 80 % capacity [16].

3. **Assumption:** We will assume that all trucks considered are Freightliner eCascadias and that all charging stations used are level 3 (DC fast charge) stations.

   Justification: Only level 2 and level 3 charging stations are viable for charging trucks, and for charging a semi truck like the Freightliner eCascadia, it would take over 17 hours for charging from 20 % to 80 % on a level 2 station, while only around 3 hours on a level 3 station [13]. Despite the decreased cost of building level 2 stations, the increased charging time will disrupt long-haul truckers' current workflow, possibly complicating the model. So, we will only build level 3 stations. We will consider only Freightliner eCascadias as NACFE provides data for this line of semi trucks. The model is simplified by considering only one line of truck.

4. **Assumption:** We will assume that all trucks can be charged to 80 %, despite any battery deterioration.

   Justification: Even though battery capacity decreases over time, a driver who only charges to 80 % may never notice [16]. The average loss of maximum charge across all electric vehicles is 2.3 % per year. The expected life time of electric semi trucks is 8.45 years [12], after which the maximum capacity of the batteries is expected to be 80.6 %.

5. **Assumption:** We will assume that half of all trucks on all highways are long-haul trucks.

   Justification: About half of US trucks are long-haul trucks [23]. Many trucks go through the five long routes given because they are big routes between cities, so the fraction of trucks that are long haul on those routes should approximately equal the nationwide estimate of one half.

6. **Assumption:** We will assume that the traffic of long-haul vehicles is roughly constant on a given road.

   Justification: Most freight traffic can be shipped at any time of day, so approximately the same amount of freight will be shipped on a given highway at any given time. We will ignore seasonal fluctuations to simplify the model.

7. **Assumption:** We will assume that electric trucks and diesel trucks cruise at the same speed.

   Justification: Since electric trucks have not been heavily tested driving on interstates, we will have them cruise at the same speed as diesel trucks for safety and energy efficiency considerations.

3.3 Developing the Model

Let L be the length of the route in miles, N_{all} be the average total trucks per day, N be the average long haul trucks per day, m_d be the energy depletion rate as percentage of total battery per mile, m_r be the energy recharge rate as percentage of total battery per minute, v be the average interstate speed in miles per hour, d be the average distance between stations in miles, and O be the number of outlets per station.

We can calculate the number of outlets per charging stations. We want to find the minimum number of outlets per station. Each truck passes round $\left(\frac{0.60}{m_d \times d}\right)$ stations before having to stop at the station and recharge. The time to recharge to 80 % from (about) 20 % is $\frac{0.60}{m_r}$ (in minutes). Therefore, dividing by stations passed between recharges, each truck spends on average) $\frac{0.60}{m_r} \times \frac{1}{\text{round}\left(\frac{0.60}{m_d \times d}\right)}$ minutes per station passed. From there, we need to multiply by the number of trucks passing per minute to get the maximum trucks per station, or the minimum number of outlets needed per station. The number of trucks passing per minute is $\frac{N}{24 \times 60}$. Rounding up, we get O:

$$O = \left\lceil \frac{N}{24 \times 60} \times \frac{60}{m_r} \times \frac{1}{\text{round}\left(\frac{60}{m_d \times d}\right)} \right\rceil$$

We can calculate the number of charging stations C given L and d. If charging stations are d miles from each other, and the route is L miles total, then we can divide L by d to get the number of charging stations needed. We could round up this number to be sure we have the route completely covered, but because the route is so long, we assume that the cities also have their own charging stations. So, we decide to round to the nearest integer.

$$C = \text{round}\left(\frac{L}{d}\right)$$

3.4 Applying the Model

The number of long haul trucks passing a point per day N will vary depending on the interstate route. The number of long haul trucks is one half the number of trucks in the US [23].

Route	Cities	v	N_{all}	N	L
1	San Antonio/New Orleans	57.4	14288.1	7144.1	533
2	Minneapolis/Chicago	57.1	12931.3	6465.7	421
3	Boston/Harrisburg	56.6	8026.6	4013.3	383
4	Jacksonville/Washington	56.2	9515.1	4757.6	701
5	Los Angeles/San Francisco	52.8	13974.9	6987.5	279

Table 1: The average trucking speed in mph [21], number of total trucks passing the highway per day [22], number of long haul trucks passing the highway per day, and the length of the route in miles.

The m_d is the depletion rate as percentage of battery capacity per mile driven. According to [17], an electric truck depletes battery at a rate of 1.23 to 1.75 kWh/km when going 80 km/hour in average traffic conditions. Both the speed and traffic conditions of this study are similar to the trucks going across the major routes. Converting from kilometers to miles, the trucks in the study were going $80\frac{\text{km}}{\text{hour}} \times \frac{1\text{ mi}}{1.60934\text{ km}} = 50\frac{\text{mi}}{\text{hour}}$. The average speed of the trucks in our study is

$$v = \frac{57.4+57.1+56.6+56.2+52.8}{5} = 56.02\text{ mph}$$

This is similar to the 50 mph used in the study. Also, the study defined average traffic conditions as not congested, and according to assumption [6], interstate highways are not congested to a significant degree. Therefore, we can use this study to calculate m_d.
Taking the average of the energy consumption rates and converting from kilometers to miles, we find that electric trucks consume

$$\frac{1.23+1.75}{2} = 1.49\,\frac{\text{kWh}}{\text{km}} \times \frac{1.60934\text{ km}}{1\text{ mi}} = 2.40\,\frac{\text{kWh}}{\text{mi}}$$

The total battery capacity is 550 kWh, and dividing by this capacity, we find that the $m_d = \frac{2.40\,\frac{\text{kWh}}{\text{mi}}}{550\text{ kWh}} \times 100\% = 0.436\frac{\%}{\text{mi}}$. The m_r is the recharge rate as percentage of battery capacity per minute charging. The truck can recharge from 20 to 80 percent in 2.5 to 3.5 hours [13]. Therefore, the average recharge time is 3.0 hours. $m_r = \frac{60.\,\%}{3.0\text{ hours}} \times \frac{1\text{ hour}}{60\text{ minutes}} = 0.3333\frac{\%}{\text{min}}$. To calculate d, we should take the maximum distance between stations so that in the worst case scenario a truck driver can always find a station before their truck dies. If a truck driver enters the highway with 20% of the battery charged, the driver could drive $0.20 \times 550\text{kWh} \times \frac{1\text{ mile}}{2.40\text{ kWh}} = 45.87$ miles. But, a truck driver could hypothetically take an exit to reverse their direction if the nearest station is before them. This would mean ideally the maximum miles between stations could be double previously calculated, but it is cumbersome and counterproductive to reverse direction and the nearest exit may be far ahead so we will multiply the distance by $\frac{3}{2}$ to provide cushion. We get $d = 45.87\text{ miles} \times \frac{3}{2} = 68.81$ miles.

Route	Cities	C	O
1	San Antonio/New Orleans	8	447
2	Minneapolis/Chicago	6	405
3	Boston/Harrisburg	6	251
4	Jacksonville/Washington	10	298
5	Los Angeles/San Francisco	4	437

Table 2: The number of charging stations and outlets that each route requires.

3.5 Discussion and Conclusion

Cost per Station According to [13], we can say that each outlet would cost an estimated $15,000 to $90,000. To simplify the math, we can then say that the average outlet costs $52,500. This means the price of providing electric infrastructure for some highways is significantly more than others – by a lot. The route from Boston to Harrisburg, for example, only requires 1506 outlets in total. However, other more intensive routes, such as the one from San Antonio to New Orleans, requires more than double that number – 3576 outlets – for a distance that is only about one third longer. However, it costs $1.25 million per mile to do something as simple as refurbish the highway in the first place [26]. This means to refurbish the 533 miles of road along Route 1, it would cost $666 million. In comparison, the building of outlets would cost $187 million. Therefore, the price for these outlets is not unreasonable for something of this scale.

Reflecting on the Model The model shows that the number of charging stations is directly related to the length of the route. Longer routes require more charging stations because an electric truck's range only goes so far, no matter how long the vehicle has been driving or the number of other trucks on the road. However, the number of outlets per charging station is independent of the length of the road itself. Instead, that amount is based on the activity of the road, or the number of trucks likely to stop at a certain charging station at a certain time. This means long roads that are also busy have significantly more unique outlets than other corridors do, such as the San Antonio to New Orleans route.

4 I Like to Move it, Move it

4.1 Restatement of Problem and Introduction

While transitioning to electric trucks can be a bit pricey, some communities would enjoy the economic and environmental benefits like good air quality that comes with the transition. Other communities surrounding the trucking corridor worry about the expenses to which the emerging charging stations will cost to develop.

To address this concern, we will consider the proportion of the local power grids that are powered by renewable energy sources. The electric semi trucks will be powered by electricity from the local power grid, so the local energy sources determine the environmental impact of the implementation of electric semi trucks. The transportation corridor with the highest percentage of renewable energy should be the first to implement the infrastructure necessary for electric semi trucks because this corridor will have the largest environmental impact. This impact is largely due to the reduction of harmful green house gas emissions such as CO_2.

4.2 Assumptions and Simplifications

1. **Assumption:** We will assume that energy exported by states is negligible.

   Justification: This assumption is necessary because our model is based on the percent of energy in local power grids that is sourced from renewable sources. It is reasonable because the exportation of energy is very costly and inefficient due to the intermittency of solar and wind and because solar and wind are concentrated sources, meaning their transmission lines are longer [24].

2. **Assumption:** We will simplify the model by considering only the proportion of energy that is produced by renewable sources.

   Justification: This assumption simplifies the model, but other factors could be added to the model as necessary in the future. By prioritizing the corridor with the highest environmental impact, the effectiveness of this investment can be maximized.

3. **Assumption:** We will assume that nuclear energy is not considered renewable energy.

   Justification: In the data set that we used, nuclear energy was not counted as renewable energy. This is reasonable because although nuclear energy produces considerably less emissions than other non-renewable sources, uranium is still a finite resource [27].

4. **Assumption:** We will focus only on the environmental impact of CO_2.

   Justification: Even though there are other greenhouse gases emitted by diesel engines, CO_2 emissions are more commonly gauged, and they correlate with total greenhouse gas emission. Considering only CO_2 emissions will simplify the model.

4.3 Developing the Model

Let $\bar{P}_r$ be the average percent electricity that is renewable for a trip. Let P_{f_i} be the percent of electricity coming from fossil fuels on the grid in the ith state. Let P_{r_i} be the percent of electricity coming from renewable energy in the ith state, which should be 1 minus P_{f_i}. Let d_i be the distance traveled in the ith state of the trip, and let D be the total distance for a trip. Let e_d be the energy in kilowatts consumed per mile for electric trucks. Let m_f be the grams of CO_2 emitted per kilowatt-hour for fossil fuels. Finally, let W be the grams of CO_2 emitted per mile for electric trucks.

Since electric trucks are only as clean as the electricity they get their power from, trucks that charge at charging stations with higher percentage of energy coming from renewable sources will have a greater impact on carbon dioxide reduction. We should, therefore, choose to build electric charging stations along routes where the percentage of energy coming from renewable sources is highest.

In order to calculate the average percentage of energy coming from renewables, we took a weighted average by determining the number of miles driven in each state and multiplying by the corresponding renewable energy percentage. We then added these values together and divided by the total miles.

$$\bar{P}_r = \frac{1}{D}\sum_{i=1}^{n}(1 - P_{f_i}) \times d_i$$

$$W = e_d \times \bar{P}_f \times m_f$$

4.4 Applying the Model

Route	State 1	State 2	State 3	State 4	State 5	Ren. Consumption
1	TX, 303	LA, 239				6.12 %
2	MN, 26.1	WI, 290	IL, 96.2			10.06 %
3	MA, 65.6	CT, 123.0	NY, 33.1	PA, 181.0		6.82 %
4	FL, 24.1	GA, 118.0	SC, 211.0	NC, 191.0	VA, 186.0	8.76 %
5	CA, 382.0					15.60 %

Table 3: Each route goes through several states. The table records the number of miles traveled in each state and the renewable percentage consumption, as a weighted average of the renewable percentage consumption for each state traveled [25].

First, e_d, the energy in kilowatts consumed per mile, as calculated in section 3, is equal to 2.40 $\frac{\text{kWh}}{\text{mi}}$. The number of grams of CO_2 emitted per mile per ton of cargo is $161.8\frac{\text{g}}{\text{mile-ton}}$. The average weight of a commercial truck payload is 30555 lbs $\times \frac{1\text{ ton}}{2000\text{ lbs}} = 15.28$ tons [29]. Therefore, a diesel truck emits $m_f = 161.8\frac{\text{g}}{\text{mi}} \times 15.28\text{ tons} = 2472.30\frac{\text{g}}{\text{mi}}$. The number of pounds of CO_2 emitted per mile driven for an electric truck is the number of kilowatts consumed per mile multiplied by the percentage of energy coming from fossil fuels multiplied by the average grams of CO_2 emitted per kilowatt of fossil fuel. The average grams of CO_2 emitted per kilowatt of fossil fuels can be estimated by dividing the number of grams of CO_2 emitted by kilowatt-hours. According to [30], fossil fuels emit $449.06\frac{\text{g}}{\text{kWh}}$. Therefore, the average grams of CO_2 emitted per mile for electric trucks is $2.40\frac{kWh}{mi} \times p_f \times \frac{449.06\text{ grams}}{1\text{ kWh}} = 1077.744\frac{\text{g}}{\text{mi}} \times p_f$.

Route	CO_2 diesel	CO_2 electric	Reduction
1	2473.20	1011.79	59.09 %
2	2473.20	969.32	60.81 %
3	2473.20	1004.24	59.40 %
4	2473.20	983.33	60.24 %
5	2473.20	909.62	63.22 %

Table 4: The grams of CO_2 emitted per mile driven for diesel trucks and for electric trucks, and the percent reduction in CO_2 emissions from diesel to electric trucks.

4.5 Discussion and Conclusion

Carbon Dioxide Savings From Table 4, we can infer that electric trucks can reduce carbon dioxide emissions by more than half. This has significant policy implications for the future. As soon as the necessary electric charging stations are installed, CO_2 can be drastically reduced in any state. Moreover, this reduction would have broader impact on U.S. emissions as a whole; 30% of emissions come from the transport sector. Electric trucks are efficient enough such that even a grid with a relatively small percentage of renewable energy can slash CO_2 emissions tremendously.

Reflecting on the Model To calculate the CO_2 emissions for electric trucks for a given trip, we took into account the number of miles driven in each state and the percentage of electricity consumption that generated from renewable energy in each state. Renewable energy consumption varies widely by trips (Table 3). However, the model demonstrates that even in the routes that use the least amount of renewable energy (Trip 1), electric trucks cut down on CO_2 emissions by 59.09 percent. This demonstrates that electrification can and will have a positive environmental impact, regardless of the initial sustainability of the route.

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5 Code Appendix

FutureTrucks.java This file contains the code written for problem 1. This program pulls together all the different factors considered and calculates the proportion of semi trucks that are expected to run on electricity for a given year. There are comments describing some of the functions below, however much of the work is discussed within the developing the model section for problem 1.

```
import static java.lang.System.*;

class FutureTrucks {
    // Get proportion of trucks that will be electric n years into the future.
    public static double getProp (int n) {
        if (n == 0) {
            return 0;  // See assumption 4
        }
        else {
            double prob = 0.15 + 0.15 * Math.sin(0.00000414 * n + 671)*(1.32*0.05
                + 0.5*0.95);
            double prevProp = getProp(n-1);
            return prevProp + prob * (1 - prevProp) / 16;
        }
    }

    public static void main (String[] args) {
        out.println("Proportion of semi trucks that are electric in 5 years: " +
            getProp(5));
        out.println("Proportion of semi trucks that are electric in 10 years: " +
            getProp(10));
        out.println("Proportion of semi trucks that are electric in 20 years: " +
            getProp(20));

        out.println("Graph data:");
        for (int i = 0; i <= 20; i++) {
            out.printf("(%d, %.3f)", i, 100 * getProp(i));
        }
        out.println();
    }
}
```