Exploring Carbon Offsets for Freight Transportation Decarbonization

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ABSTRACT

Carbon offsets present a mechanism to leverage corporate sustainability commitments to fund fleet renewal programs, decommissioning aging trucks and replacing them with greener vehicles. This study evaluates the feasibility of this approach from a financial and logistical perspective. First, the demand for transport carbon offsets is forecasted using inputs from global greenhouse gas emissions data, corporate sustainability commitments related to transportation, and CDP corporate disclosure data, pricing the potential mature market size at over $300M per year. Secondly, a novel method is defined to quantify the avoided emissions from decommissioning for a variety of vehicle types, leveraging industry standards for carbon accounting such as the Global Logistics Emissions Council Framework. Finally, the study breaks down the costs associated with a fleet renewal carbon offset program, and provides operational recommendations and best practices for fleet renewal programs. The analytical tools and frameworks developed in this study can be utilized to support the design and implementation of a transportation-based carbon offset program that has the potential to drive significant impact in global carbon emissions reduction.

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~ Abdelrahman Hefny

Table of Contents

Table of Contents **4**

List of Figures **6**

List of Tables **6**

1. Introduction **7**

1.1 Road Freight Transportation is a Significant Driver in Global Carbon Emissions .. 7

1.2 Exploring Innovative Approaches to Drive Freight Decarbonization 8

2. Literature Review **11**

2.1 Introduction 11

2.2 Freight Transportation 11

2.3 Freight Carbon Emissions 12

2.4 Carbon Offset Programs 13

2.5 Carbon Offset Programs in Transportation 14

2.6 Fleet Renewal Programs 15

2.7 Previous Fleet Renewal Programs 15

2.8 Incentive Plans and Decommissioning 16

2.9 Corporate Sustainability Pledges and Targets 17

2.10 Quantifying Carbon Emissions for Transport 18

2.11 Summary 20

3. Freight Carbon Offset Program Supply & Demand: Data and Methodology **21**

3.1 Modeling Potential Demand for Freight Carbon Offsets 21

3.2 Modeling the Value of Market Demand 23

3.3 Carbon Savings Potential 24

3.3.1 Quantifying Carbon Emissions for Transport 25

3.2.2 Scope 1 & Scope 3: 27

3.3.2 Black Carbon Calculation 29

4. Freight Carbon Offset Program Supply & Demand: Results **31**

4.1 Modeling Potential Demand for Freight Carbon Offsets 31

4.2 Modeling the Value of Market Demand 33

4.3 Carbon Emissions Calculations Results 34

4.4 Offset Potential 36

4.5 Initial Estimated Costs: 37

4.5.1 Cost-Based Method 37

5. Limitations and Future Research **41**

5.1 Potential Demand for Freight Carbon Offsets Limitations 41
5.2 Modeling the Value of the Market Demand Limitations 42
5.3 Carbon Calculations Limitations 42
6. Fleet Renewal Program Design Recommendations 44
6.1 Initial Considerations for Program Design 44
6.1.1 Program Objectives 44
6.1.2 Scope 46
6.1.3 Vehicle Target 46
6.1.4 Enforcement 46
6.1.5 Policy Complements 47
6.2 Vehicle Standards 48
6.2.1 Other Potential Carbon Offset Mechanisms 48
6.2.2 Decommissioned Vehicle Standards 49
6.2.3 Vehicle Replacement Standards 51
6.3 Program Design 52
6.3.1 Stakeholders and Roles 52
6.3.2 Funding 52
6.3.3 Pricing and Incentives 53
6.3.5 Communication and Program Administration 56
7. Conclusions 57
Citations 59

List of Figures

Figure 1: Emissions covered in the GLEC Framework vs. the Black Carbon Methodology (GLEC Framework, 2019) 19
Figure 2:Percent Increase in GHG Emissions (2015 - 2050) 25
Figure 3: The CO_2e for Heavy Duty Shipments with Varying Distances and Payloads 28
Figure 4: Road Freight Emissions Carbon Offset Market: Scenario Comparison (2025) 32
Figure 5: Road Freight Emissions: Carbon Market Offset Market Across Time 33
Figure 6: Road Freight Emissions: Carbon Market Offset Size in $ 34
Figure 7: Tons CO_2e For Active African Vehicle Types Over 1 Year 35
Figure 8: g BC for African Vehicle Types Over 1 Year 35
Figure 9: Best Practices in Fleet Renewal Program Design 44

List of Tables

Table 1: Transportation Offset Commitment Reporting Organizations and Citations 22
Table 2: Estimating Offset Demand Scenarios and Assumptions 22
Table 3: Sample Carbon Offset Prices 24
Table 4: African Diesel Truck Types and GLEC Default Values 26
Table 5: Scope 3 Ton CO_2e for Active Heavy Goods Truck Over 1 Year 29
Table 6: BC Emissions for an Active Heavy Goods Truck for 260 Shipments a Year 30
Table 7: Estimating Offset Demand Scenario Forecasts (2025) 31
Table 8: Average African Active Truck Conditions for 1 Year 34
Table 9: Emissions for Active Truck Types over 1 Year 34
Table 10: Ton CO2e for Active Truck Types Over Operating Lifetime 36
Table 11: Potential CO2e Avoided at Purchase Based on Truck Remaining Years of Operation 37
Table 12: Operating Condition Example 40
Table 13: Cost of Ton CO2¬e for Heavy Goods Vehicle With Varying Market Value 41
Table 14: Selected Fleet Renewal Program Decommissioned Vehicle Standards 50
Table 15: Selected Fleet Renewal Program Vehicle Replacement Standards 51
Table 16: Select Fleet Renewal Programs' Total Budget 53
Table 17: Select Fleet Renewal Programs' Renewal Vehicle Funding Strategy 54
Table 18: Heavy Truck Prices, in USD(Teravaninthorn & Raballand, 2009) 56
Table 19: Method of Truck Purchase Financing (Teravaninthorn & Raballand, 2009) 56

1. Introduction

1.1 Road Freight Transportation is a Significant Driver in Global Carbon Emissions

Freight transportation emissions accounted for 8% of total global carbon emissions in 2015 (International Transport Forum, 2019), with the transportation sector set to become the second largest contributing industry to global carbon emissions. More than 90% of the transportation industry operates using fossil fuels (International Transport Forum, 2018), and nearly all heavy-duty freight trucks use diesel fuel. Beyond their climate impacts, emissions from diesel fuel combustion are recognized as a Class 1 carcinogen and have been linked to millions of deaths every year (Miller, 2018). Global freight demand is expected to triple between 2015 and 2050, driving a doubling of freight emissions by 2050 (International Transport Forum, 2019). Population growth, economic development, international trade, and expansion of e-commerce are all factors contributing to growth in transportation and freight demand (International Transport Forum, 2019). Thus, transportation is estimated to become the most carbon-intensive sector, overtaking energy, by 2040 (International Energy Association, 2018).

Decarbonization refers to the elimination of carbon from an operation or business. Heavy-duty trucking has been identified as a difficult to decarbonize sector (Energy Transitions Commission, 2018). Low-carbon transportation and freight technologies, such as commercial fleet electrification, are not widely implemented. Electric fleet are costly, available in limited quantities, and require substantial widespread charging infrastructure before they can be widely adopted (GreenBiz, 2018). Many newer vehicles have been developed in compliance with emissions standards such as Euro VI[1], ensuring that newer vehicles emit lower emissions than their predecessors. However, without policy or legislative levers supporting low-carbon options; cost, time, and efficiency are likely to be the key factors in choosing transportation modes. In the freight sector, low cost and efficient freight options are still largely carbon intensive.

[1] The European Union governs vehicle emissions standards by a set of standards known as the Euro Standards.(European Commission, n.d.)

Decarbonization of the freight sector is largely stalled due to these factors, although there is increasing demand for more sustainable transportation options (DHL, 2019). Innovative approaches within the freight sector and its myriad customers will be needed to reach critical climate targets, United Nations Sustainable Development Goals, and global public health objectives.

1.2 Exploring Innovative Approaches to Drive Freight Decarbonization

This capstone will investigate and develop an innovative approach to transportation decarbonization, leveraging carbon offset investments to fund fleet renewal programs. *Carbon offsets* are a method for mitigating carbon emissions wherein an organization purchases a certificate that represents the reduction of carbon dioxide emissions in one place in order to compensate for emissions the purchasing organization generated elsewhere. Carbon offset programs are often operated by international organizations, and certified by entities such as the Gold Standard. An example of a carbon offset may be a company offsetting its transportation emissions to a project in South America designed to prevent deforestation, or replacing cookstoves in Africa with lower emissions appliances. A company will purchase enough ‘offsets’ for a certain amount of emissions, and the carbon offset project the company funds will save this amount in emissions. Companies in carbon-intensive industries are increasingly turning to carbon offsets to mitigate their emissions and meet their emissions goals.

Carbon offset market *demand* refers to organizational interest in purchasing carbon offsets; while carbon offset market *supply* refers to the availability of projects and programs that conduct emissions reduction. Carbon offset demand may be driven by governments purchasing offsets seeking compliance with emissions regulations (mandatory market), or by organizations as a corporate sustainability initiative (voluntary market). The voluntary and mandatory markets differ in offerings and price trends (Hamrick & Gallant, 2018). The mandatory market is much larger, with nearly twenty times the volume of carbon traded and purchased annually (European Commission, 2017). This capstone will focus on the growing voluntary market.

The voluntary carbon offset market saw a 50% increase in volume trades between 2016 and 2018, and has a total market value of $300M (Forest Trends, 2019). This is anticipated to grow significantly in the coming years, as sustainability gains traction as a corporate focus. High profile organizations such as Amazon (Amazon, 2019), Shell ("Shell invests in nature as part of broad drive to tackle CO2 emissions," 2019), Lyft (Fehrenbacher, 2018), Etsy (Etsy, 2019) have all pledged to become carbon neutral, and will likely use carbon offset purchases to reach this goal.

As noted above, the supply of carbon offset programs spans many sectors, including forestry, renewable energy, and waste disposal (Forest Trends, 2019). Transportation-related carbon offset programs are small, representing less than 1% of the volume of CO_2 traded in the voluntary market in 2018 (Forest Trends, 2019). However, the volume of transport related offset programs purchased tripled between 2017 and 2018 (Forest Trends, 2019). The asymmetry between transportation's contribution to carbon emissions and relatively small portion of offset program represents an opportunity for growth; as companies looking to offset transportation emissions may wish to align their offsets to be transport related.

Fleet renewal programs represent an opportunity for a transport-focused carbon offset market. Fleet renewal programs refer to upgrading an organization's freight vehicles. Fleet renewal programs often take the form of adopting emerging or best in class technologies with new vehicles. However, there are significant sustainability opportunities in directing fleet renewal programs towards decommissioning aging, high-emissions vehicles or fleets. Heavy duty vehicles manufactured prior to the year 2000 represent less than half of global fleet, but contribute nearly to three-quarters of global black carbon emissions (Miller & Jin, 2018). Aging fleet disproportionately contribute to freight carbon emissions, as they may have been manufactured prior to the adoption of emissions standards or technologies such as particulate filters (Miller & Jin, 2018). Carbon offsets present an opportunity to finance and encourage the implementation of fleet renewal programs targeting these vehicles (Greene & Façanha, 2019).

Although the decision to invest in or make fleet changes is made by individual businesses, carbon offsets may represent an opportunity to provide financial incentives to these businesses, encouraging them to make decisions aligned with a sustainability-driven approach.

1.3 Capstone Approach

This capstone aims to explore the potential of accelerating the decarbonization of road freight transport systems through voluntary carbon offset programs. This project will develop a model to analyze the potential global market for transport related carbon offsets, quantify the potential scale of impact for such programs, and analyze best practices in implementing fleet renewal programs. The project will focus on geographies with aging truck fleets, which are concentrated in emerging economies.

A thorough literature review will assess available scholarship around freight transportation, greenhouse gas emissions, fleet renewal programs, and corporate sustainability commitments. To develop the demand for transportation related carbon offsets, we analyze current transportation related corporate climate goals and the carbon offset market. Key information sources include the 2018 CDP carbon emissions disclosure dataset ("CDP," 2019a), company corporate sustainability reports, and carbon offset market data. Insights into these areas will set a foundation for assessing the potential market for and impact of carbon offsets in the freight transportation industry, as well as implementation costs and structures formulating the price of offsetting carbon through such programs. Data on existing fleet renewal programs will be collected and assessed to create a framework for quantifying and modeling the market implementation costs. We also develop a calculator which can calculate the cost for offsetting one ton of CO_2 through truck decommissioning, considering input data such as, vehicle type, level of activity, and vehicle market value.

This capstone will contribute to scholarship by conducting the unique analyses of understanding the potential market and impact of emissions avoidance as a result of fleet renewal programs, quantifying the cost of fleet renewal carbon offsets, and providing operational recommendations by analyzing best practices in fleet renewal programs. The analytical tools and frameworks developed could be utilized to understand, design, or implement such a program to drive significant impact in global carbon emissions reduction.

2. Literature Review

2.1 Introduction

Carbon offsets have the potential to be leveraged to fund investments in fleet renewal programs, supporting the transition to a low-carbon freight transportation network. This literature review will explore the applicability of such programs by assessing the carbon emissions from freight transportation, fleet renewal programs, and carbon offset programs, setting the context for the methodology and results of this capstone. Within freight transportation, the literature review will explore the dynamics of the freight transportation industry and its associated emissions. This paper will also explore the carbon offset market and corporate offsetting pledges that pertain to transportation as well as existing fleet renewal programs, incentive plans, and carbon emissions calculations methods. Insights into these areas from available literature will set a foundation for assessing the potential market and impact for carbon offsets in the freight transportation industry, as well as implementation costs and structures.

2.2 Freight Transportation

Freight transportation is a key component in many global supply chains. Maritime freight is the most common mode of transport, moving over 75% of goods by weight, with road transportation representing 18% of freight activity, and aviation and rail representing the remaining weight of goods (International Transport Forum, 2019). With an eye towards the future, global freight demand is expected to triple between 2015 and 2050 (International Transport Forum, 2019). In developing countries specifically, population growth, economic development, international trade, and expansion of e-commerce are all factors contributing to the growth in transportation and freight demand. The road freight transportation industry, in contrast to the international aviation or maritime freight industry, is often concentrated in domestic transportation markets, or operated by small businesses (Energy Transitions Commission, 2018). As a result, governance, incentives, and access to capital investment funds for these firms may differ from the global aviation or maritime industries, which should be considered within fleet renewal programs.

2.3 Freight Carbon Emissions

Greenhouse gas (GHG) emissions from the transport sector account for 23% of total GHG emissions, making it the second largest emitting sector worldwide (International Transport Forum, 2019). Freight transportation emissions accounted for 8% of total global carbon emissions in 2015; for a total of 2.9 billion tons of CO_2 (International Transport Forum, 2019). Although road transportation makes up less than 20% of freight activity, it contributes to nearly 60% of CO_2 emissions (International Transport Forum, 2019). Nearly all heavy-duty freight trucks use diesel fuel. Growth in global freight demand is projected to drive an increase in transport related CO_2 emissions of 60% by 2050 (International Transport Forum, 2019), if emissions continue at current rates, this will drive transportation to be the most carbon intensive sector, overtaking energy, by 2040 (International Energy Association, 2018).

Engine standards are set in place that specify the limits and benchmarks for exhaust emissions of combustion engines. Different countries use different standards, yet with similar criteria. One such standard used and applied to countries belonging to the European Union is the Euro Standard for vehicle emissions. Over 120 countries have on road diesel vehicles emitting carbon and particulate levels exceeding those of the Euro VI standards (Miller & Jin, 2018). Although there has been a growth in compliance with global emissions standards such as Euro VI, heavy-duty vehicles manufactured before the Euro-III standards disproportionately contribute to freight carbon emissions. They represent less than half of global fleet, but contribute nearly three-quarters of global black carbon emissions (Miller & Jin, 2018). Developing countries’ freight emissions will grow at a faster rate than developed countries, driven by economic growth and the widespread presence of older vehicles, which are often available at lower cost or resold to developing markets (Greene, 2017). According to the International Energy Agency, the number of vehicles approaching their end-of-life is expected to increase. At the same time, as demand for green vehicles rises in the developed countries, the number of old, near to being scrapped vehicles, that are being sent to and sold to developing countries, specifically, in Africa increases.

2.4 Carbon Offset Programs

Carbon offsets are a method for mitigating carbon emissions wherein an organization purchases a certificate that represents the reduction in emissions of carbon dioxide in one place in order to compensate for emissions the purchasing organization made elsewhere. Carbon offsets may be mandatory (e.g., for compliance with emissions caps of the Kyoto Protocol), or voluntary, as a corporate sustainability initiative. A 2014 review of the CDP dataset revealed that 17% of companies utilized carbon offsets (Ecosystem Marketplace, 2016). However, in a *Newsweek* 2019 survey of major companies, half of companies reported that carbon offsets would be a facet of their sustainability strategy (Shields & Langer, 2019). Increasingly, companies are turning to carbon offsets to invest in clean energy aiming to mitigate their emissions and meet their emissions goals. The voluntary carbon offset market saw a 50% increase in volume trades between 2016 and 2018, and has a total market value of $300M and 98.4 Mt of CO_2 (Forest Trends, 2019).

Carbon emissions have a cost that reflects carbon emissions' negative impact on the environment and society. Investments in carbon offsets are one way to represent how companies consider that cost, and policy interventions like a carbon tax are another. For example, the United States Environmental Protection Agency (EPA) in 2015 priced the environmental and social cost of carbon at an average $36 USD for every ton of carbon emitted (Gold Standard, 2017). Carbon offset prices don't necessarily mirror a carbon tax or environmental externality cost, but rather tend to be variable and inconsistent, particularly in the voluntary market (Gold Standard, 2017). This is mainly because carbon pricing is affected by supply and demand, project cost, as well as the additional benefits provided by the project. Carbon offsets lack a centralized marketplace for companies to purchase (Forest Trends, 2017), and supply has historically outstripped demand. The Fairtrade Carbon Credit Pricing Model is a method that calculates the minimum cost of a credit given the average cost of the project to ensure the project's sustainability and long-term benefit to the community, which is used in this study to estimate the cost of offsetting carbon through fleet decommissioning programs (Gold Standard, 2017).

2.5 Carbon Offset Programs in Transportation

Renewable energy, forestry, and land use are the most common categories for carbon offset initiatives. Carbon offset programs applied to freight transportation are rare, representing less than 1% of CO_2 offsets in the voluntary market with a total of 0.3 $MtCO_2e$ (Forest Trends, 2017). This signifies a substantial opportunity for growth using existing methods and systems (Greene & Façanha, 2019).

There is interest in addressing hard-to-decarbonize transportation emissions using carbon offsets in the aviation sector. The aviation industry has adopted carbon offsets as their main emissions mitigation tool through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) program, with current projections estimating demand for over three billion tons of carbon offsets through 2025 (Bailis, Broekhoff, & Lee, 2016) (International Civil Aviation Organization, n.d.).

Beyond the aviation sector, myriad companies have pledged to buy carbon offsets related to transportation. For example, Shell, Lyft, Etsy, and Anglo-American have made commitments to offset their freight transportation-based carbon emissions through offset programs; setting a precedent for further development in this area. Examples of such projects are shown below:

- **Shell** – In Europe, Shell will offset purchases at Shell oil-stations of diesel fuel to be offset either automatically, or at a low cost of 1 cent/liter to consumer with an initial investment of $300 million in offsets ("Shell invests in nature as part of broad drive to tackle CO2 emissions," 2019).
- **Lyft** - In 2018, the ride sharing company committed to offsetting all rides taken globally. This has resulted in over a million metric tons of carbon offset (Fehrenbacher, 2018).
- **Etsy** – In 2019, Etsy, a leading ecommerce company, committed to offsetting 100% of carbon emissions from shipping of its products (Buddie, 2019).

While there is an interest in carbon offsets to mitigate transportation emissions, there is an untapped potential to apply these offset funds within the transportation sector.

2.6 Fleet Renewal Programs

Fleet renewal programs incentivize organizations to update their vehicles, cars, airplanes, or ships to newer models by offering payments to buy back out-of-date vehicles or provide vouchers for purchasing new equipment.

Fleet renewal programs have been implemented in many countries for a variety of reasons, including providing economic stimulus to the automobile industry, decreasing emissions, and improving road safety (UNEP, 2011). Updating a company's fleet can lead to additional cost-savings as a result of improved fuel efficiency and lower maintenance costs. A more sustainable fleet can make a carrier more attractive to customers aiming to lower their carbon footprint (Kholod, Malyshev, Evans, Lipka, & Gusev, 2015). National or local governments and "green freight" programs are often the implementers; setting up programs to incentivize fleet replenishment.

This report investigates previous fleet renewal programs to identify best practices aiming to develop a model for carbon saving calculation as a result of fleet renewal programs and decommissioning.

2.7 Previous Fleet Renewal Programs

An analysis of fleet renewal programs targeted at heavy-duty vehicles conducted by Posada, Francisco; Wagner, David Vance; Bansal, Gaurav; Fernandez, 2015 unveiled programs in the United States (National Clean Diesel Campaign), China (Vehicle Scrappage Programs), Mexico (Modernize Federal Road Transportation), and Chile (Swap Your Truck); with local US programs in California in the Port of Los Angeles, and Indiana, such as the Indiana Clean Air Project (Posada, Wagner, Bansal, & Fernandez, 2015) (USA v. Volkswagen AG, 2016). In this capstone, Section 6 Fleet Renewal Program Design Recommendations, evaluates various design elements for fleet renewal programs and analyzes best practices. The following section will highlight the origins and vehicle replacement standards for two fleet renewal programs.

The Clean Truck Program (CTP) is a fleet renewal program that was established by the Port of Los Angeles in 2009 that decreased air pollution from the Port's drayage truck emissions by more than 90 percent ("Port of Los Angeles Clean Truck Program," n.d.). To achieve this objective the

CTP set a cap banning trucks that do not meet 2007 emissions standards set by the Environmental Protection Agency (EPA). In order to facilitate this process, the CTP established a Concession Program that allowed carriers to apply for funding for new trucks provided that they abide by certain guidelines, enabling the conversion to more environmentally friendly vehicles.

As part of the VW settlement funds, VW agreed to plead guilty and paid a penalty of $35 million (USA v. Volkswagen AG, 2016). The state of Indiana received a $10 million grant to launch the Indiana Clean Air Project. The project targets diesel vehicles and is divided into two branches, engine retrofitting and vehicle replacement. Engine retrofitting entails replacing old engines with engine models 2019 or newer, while vehicle replacement covers the decommissioning of the old vehicles and replacing them with newer and cleaner models (Greaney, 2019). The project covers several types of diesel-fueled vehicles, engines, and equipment that are eligible to receive the grant. These vehicles include buses, locomotives, marine engines, and medium and heavy-duty trucks. Various stakeholders are eligible to apply for the grant, from public government-run fleet entities to privately owned fleet operators. The project follows the EPA and the California Air Resource Board (CARB) standards for operation and has embedded those standards in its reporting and evaluation criteria; however, information on the methodologies used to quantify the reduction in emissions is not available. The methods followed for engine retrofitting, installation of engine or vehicle upgrades and replacements are adopted from the EPA and CARB as mentioned previously (Seals, 2019).

2.8 Incentive Plans and Decommissioning

Policies and incentives can be used to support effective fleet renewal programs, such as vehicle registration management, inspection and maintenance testing, fleet labeling systems, and a defined scrappage program, which may include vehicle dismantling (Shao et al, 2016). A robust fleet renewal program also requires communication, education, and targeting of potential consumers. Incentives to encourage fleet renewals can include direct subsidies – scrappage credits to count towards vehicle renewal, tax reductions, and decreased registration fees; as well as indirect subsidies- including access (or lack of) to certain driving zones or parking areas depending on vehicle compliance (Shao et al., 2016). Financial incentives for fleet renewal programs should cover the costs of scrapping and address the cost differential needed for consumer or fleet operators to purchase a new vehicle.

Fleet renewal programs in Mexico and Chile faced challenges in enrolling small fleet operators; which are less likely to have access to capital for fleet upgrades, operate the oldest vehicles with higher emissions, and are likely to purchase vehicles (Miller, 2016). Proposed solutions for this included granting small scale fleet operators the ability to receive a financial certificate, which they could then sell in an exchange to other vehicle consumers, giving them the flexibility to use the proceeds towards procuring a used vehicle.

2.9 Corporate Sustainability Pledges and Targets

Global agreements have spurred dialogue and action on emissions reduction across governments. The Intergovernmental Panel on Climate Change (IPCC), a UN entity, issued a warning to cut emissions to net zero by 2050 to avoid further global impacts on climate change (Allen et al., 2018). The 2015 Paris Agreements garnered 195 country signatories committing to emissions reduction (UNFCC, 2015). In the private sector, global corporations are increasingly initiating sustainability pledges, driven by increasing customer scrutiny on corporate social responsibility and sustainability. Additional incentives for emissions reduction and sustainability initiatives include attracting investment, decreasing impact on operations due to climate change, and even avoiding climate litigation (Shields & Langer, 2019). A poll led by Newsweek of 300+ global corporations noted that 60% of companies stated that climate change had impacted their business' operations. Of those companies surveyed, nearly 75% noted they planned to reach net zero emissions by 2030; ahead of the IPCC's target date (Shields & Langer, 2019). Of note – 70% of companies cited that transportation and distribution of goods would be a targeted value chain for emissions reduction (Shields & Langer, 2019).

Data regarding corporate emissions and reductions targets are available in the CDP website. Of note, nearly 75% of the Fortune 500 companies report to the CDP (CDP, 2019b). The nexus of international policies and corporate interest in emissions reduction, including transportation as an emissions reduction lever, introduces the opportunity for transportation related carbon offset programs to emerge. The CDP data will provide substantial insight regarding potential market sizing for this initiative.

2.10 Quantifying Carbon Emissions for Transport

Accurately quantifying carbon emissions is the first step in taking corrective data driven decisions, and is necessary in order to structure and measure the success of fleet renewal programs and validate carbon offset programs. This project will leverage two existing methods for estimating carbon emissions for freight; the Black Carbon Methodology for the Logistics Sector and the Global Logistics Emissions Council (GLEC) Framework, for black carbon and greenhouse gas emission calculations respectively. These methods aim to standardize calculation methods for freight carbon emissions accounting.

Following the Greenhouse Gas Protocol, there are three categories of activities, or scopes of emissions: (WRI and WBSCD, 2015)

- **Scope 1**: emissions that are produced as a direct result of assets operated or owned by the reporting company. This includes vehicles, which is the focus of this study.
- **Scope 2**: indirect emissions as a result of energy usage, such as electricity and heat used to operate the reporting company's assets.
- **Scope 3**: take into consideration the indirect emissions as a result of the reporting company's supply chain operations.

Fuel consumption when calculating scope 1 and scope 2 fuel emissions is generally based on primary data. Fuel consumption factors are used to calculate the fuel efficiency of freight based on type of fuel in units of liters of fuel consumed by moving one ton for one-kilometer unit. Since data is not available for calculating scope 3 emissions in the supply chain, these emissions are calculated based on activity, using a carbon intensity factor per ton-kilometer. These factors vary based on fuel type, engine type, and operating conditions (GLEC Framework, 2019). As a result of the varying modes of transport used over the journey of a shipment, data on the type of vehicle, distance traveled, and kind of fuel used is not always available, which increases the complexity of calculations. Different arrangements of the data can be used depending on the level of accuracy and their availability as well as the transport chains of the company (GLEC Framework, 2019).

The study uses emissions from fuel over its entire life cycle from “Well-to-Wheel (WTW)” (GLEC Framework, 2019). WTW emissions are the fuel life cycle emissions divided into two counterparts, from Well-to-tank (WTT) and from Tank-to-Wheel (TTW). Emissions from each stage in the fuel life cycle differs from one type of fuel to the other.

Figure 1 shows the distinct difference between the GLEC Framework and the Black Carbon Methodology, which are the industry standards used for emissions calculation (Greene, S., 2017, and Greene, S. & Lewis, 2019). As opposed to the Black Carbon Methodology that focuses only on black carbon emissions, the GLEC Framework provides standardized methods for calculating carbon dioxide emissions as well as several accompanying GHGs that contribute to global warming and negative health and environmental influences.

Figure 1: Emissions covered in the GLEC Framework vs. the Black Carbon Methodology (GLEC Framework, 2019)

By using the same principles adopted in the Greenhouse Gas Protocol and the GLEC Framework, the Black Carbon Methodology maintains consistency in its accounting methods to maintain a streamlined method for standardization (World Business Council for Sustainable Development & World Resources Institute, 2011). Black carbon is a primary ingredient of particulate matter, a widely regulated air pollutant from fossil fuel combustion. There is a wide range of average emissions factors for black carbon and particulate matter emissions from transport; however, the most challenging aspect is not in calculation, but in allocating the most suitable and appropriate figures to the actual settings and operating conditions. Emissions for black carbon can be calculated along a spectrum, referred to as bronze, silver, and gold, varying in certainty respectively depending the available data (Greene, 2017).

The GLEC and the Black Carbon methodologies provide a robust analytical framework to evaluate carbon emissions reduction via fleet renewal programs to be used for this capstone. Despite the difference in scope, both frameworks share the same methods and principles for calculations in efforts to create a standardized method allowing for comparison. However, the Black Carbon Methodology and the GLEC Framework do not directly address the emissions savings from fleet renewal programs, nor the emissions related to the maintenance, production, and scrappage of vehicles. This study builds on these methodologies towards the development of a method to quantify emissions saving from fleet renewal programs and the decommissioning of dirty vehicles.

2.11 Summary

Available literature and research provide key insights into the possibility of applying carbon offsets to decarbonize freight. Freight transportation is a sizable and growing contributor to global carbon emissions. Current freight emissions are disproportionately driven by aging vehicles, often in developing countries. Fleet renewal programs that decommission these vehicles and replace them with vehicles in compliance with current emissions standards would lead to significant emissions avoidance. There are available lessons learned regarding prior successful fleet renewal programs that are considered to build a successful transportation offset program, though a need remains for methods that specifically address carbon accounting for these types of offsets

Carbon offset programs are growing in scale and impact; although transportation related carbon offset projects are still rare. This capstone will contribute to scholarship by conducting the unique analyses of understanding the potential freight carbon offset market and impact of emissions avoidance as a result of fleet renewal programs. The project will leverage existing data around freight transportation emissions growth and corporate climate targets to model the potential market. Using existing frameworks this project will quantify the carbon reduction potential of fleet renewal carbon offsets and develop an economic feasibility study for fleet renewal programs funded through carbon offsets.

3. Freight Carbon Offset Program Supply & Demand: Data and Methodology

This section of the capstone provides background on the methodology and data used to evaluate the potential demand and market value for a carbon offset program, the potential emissions avoidance that it could drive, and the funding required to administer such a program.

3.1 Modeling Potential Demand for Freight Carbon Offsets

Carbon offset market *demand* refers to the market for organizations to purchase carbon offsets, quantified in metric tons of carbon dioxide equivanlance (CO_2e). Our capstone considered several strategies in developing the potential market demand for a freight-related carbon offset program. Using a top down approach, we forecast market size by presuming that a certain proportion of total freight emissions would be offset. To utilize a bottom up approach, we evaluate existing transport related offset programs or individual companies' commitments to carbon neutrality to develop a global estimate. We developed a series of scenarios that fell under three types: a proportion of global freight emissions, CDP reporting, and corporate commitments and existing initiatives.

The International Transport Forum (ITF) reports global freight emissions estimates (International Transport Forum, 2019). Within the global road freight scenarios, we assume that 5% and 10% of these emissions could be offset by the time the program reaches maturity. Of note, the ITF also proposes a 2.7% annual emissions growth rate in its projections. This annual growth figure is used throughout our scenarios to project forward past 2020.

CDP is a global initiative that allows corporations and organizations to disclose their Scope 1, 2, and 3 emissions ("CDP," 2019a). Emissions data reported into CDP composes a limited proportion of global emissions – but does feature reporting from organizations that are self-selected towards acting on emissions. We developed two scenarios – one of all Scope 3 freight emissions, and one of all road freight emissions. Of note, less than 1M tons of CO_2 are attributed to road freight in the CDP data – which is less than 1 percent of global road freight emissions. This is due to only a portion of the market reporting, as well as to data inconsistencies in labelling the mode of transport.

Lastly, we evaluated corporate commitments and existing initiatives. Table 1 documents a variety of logistics and freight-intensive organizations which have committed to being carbon neutral through the next two decades. These organizations are likely to use offsets to reach their target, and a transportation-related offset program would allow them to match their offsets with their emissions-generating activities. The aggregation of these organizations' emissions represents a potential market size scenario. Also considered are existing transportation-related carbon offset programs, and the CORSIA aviation program.

Table 1: Transportation Offset Commitment Reporting Organizations and Citations

Organization	**Citation**
Lyft	(Anzillotti, 2019)
Etsy	(Etsy, 2019)
Formula One	(Mitchell & Cooper, 2019)
K+N	(Kuehne + Nagel, 2018)
DHL	(DHL, 2018)
FedEx	("CDP," 2019a)
UPS	("CDP," 2019a)
Amazon	(Amazon, 2019)

The scenarios developed are documented in **Table 2: Estimating Offset Demand Scenarios and Assumptions**.

Table 2: Estimating Offset Demand Scenarios and Assumptions

	Scenario	Assumption Notes
Global Road Freight Carbon Emissions (International	Scenario 1: Moderate Overall Road Freight %	• *Estimates 5% of global road freight emissions are offset.*
	Scenario 2: Aggressive Overall Road Freight %	• *Estimates 10% of global road freight emissions are offset.*
Overall CDP Report Data: Freight or Road Emissions ("CDP," 2019a)	Scenario 3: Aggressive Offset Agenda: CDP Reporting Companies - Scope 3 (All Freight Method)	• *All scope 3 Freight Emissions, both upstream and downstream, reported by companies to CDP in 2018. Most CDP data are not delineated by transport mode; this model assumption presumes 20% of CDP freight emissions would compose the road freight transportation offset market.*
	Scenario 4: Aggressive Offset Agenda: CDP Data - Scope 3 (Road Only)	• *Scope 3 Freight Emissions, road freight, reported by companies to CDP in 2018. The model assumption presumes that all organizations reporting Scope 3 Road Emissions would offset 100% of these emissions.*
Corporate Commitments &	Scenario 5: Transportation-related Carbon Offset Commitments	• *Aggregates emissions from a subset of existing public corporate commitments for voluntary transportation-related offsets and total reported freight emissions for major logistics providers targeting carbon neutrality.*

	Scenario	Assumption Notes
		• *See **Error! Reference source not found.** for information regarding entities included.*
	Scenario 6: 2016 – Transport Carbon Offset Projects	• *This scenario aggregates the reported offsets of existing transportation related carbon offset projects in 2016, although they may not be targeting fleet renewal or road freight. Of note - this is <1% of total carbon offsets sold in the voluntary carbon offset marketplace.* • *This could be considered a "floor" for transportation related offsets, tracking the total market several years ago. No growth rate applied.* (Ecosystem Marketplace, 2016)
	Scenario 7: CORSIA Emissions	• *This scenario presents the estimated annual emissions offsets via the CORSIA program, which will be used to offset airline emissions.* • *This figure is to be used for comparison purposes. No growth rate applied.* (International Air Transport Association, n.d.)

An evaluation of the scenarios led to several key insights:

- Although CDP data is a valuable source for emissions data for individual organizations, it systemically understates global totals. As such, aggregate totals from CDP, and Scenarios 3 and 4, were not included in the final quantitative model.
- Scenario 6: 2016 Transport Carbon Offset Projects, and Scenario 7: CORSIA Emissions are unlikely to align with the road freight carbon offset demand, but could provide a range. CORSIA estimated annual offsets could be considered a potential maximum range, as this will be a mandatory global standard, and Transportation Carbon Offset Projects available as of 2016 could constitute a minimum value.

As such – our recommendation is to develop the market demand based on the Global Road Freight Carbon Emissions Scenarios (Scenarios 1 and 2) as well as the current transportation emissions avoidance commitments (Scenario 5).

3.2 Modeling the Value of Market Demand

Prices in the voluntary carbon offset market can vary widely, as demonstrated in **Table 3: Sample Carbon Offset Prices**. Offset prices are typically priced per metric ton of CO_2. Factors contributing to carbon offset price can include the nature of the offset project, project implementation cost, and the volume of CO_2 being purchased to offset (Hamrick & Gallant, 2018).

Table 3: Sample Carbon Offset Prices

Price Model	Cost per metric Ton ($USD)
Average Transportation Carbon Offset Price (Hamrick & Gallant, 2018)	$0.30
Average Voluntary Carbon Offset Price (Hamrick & Gallant, 2018)	$3.00
CORSIA Emissions Costs - 2025 (International Civil Aviation Organization, n.d.)	$11.20

The effective carbon offset price strongly influences the program's incoming revenue, and funding availability to incentivize vehicle decommissioning.

3.3 Carbon Savings Potential

This section of the capstone aims to calculate carbon emissions savings as a result of vehicle decommissioning, specifically considering diesel-operated light, medium, and heavy-duty trucks. In order to do so, the capstone starts by studying vehicle emissions from the most carbon intensive regions. Although policies have been set it place aiming to lower freight emissions, carbon emissions are projected to increase in some regions more than others.

Based on projections from the ITF, built on current and ambitious emissions reduction policies, the percentage increase in emissions per region was calculated building upon ITF data from the year 2015 to 2050.

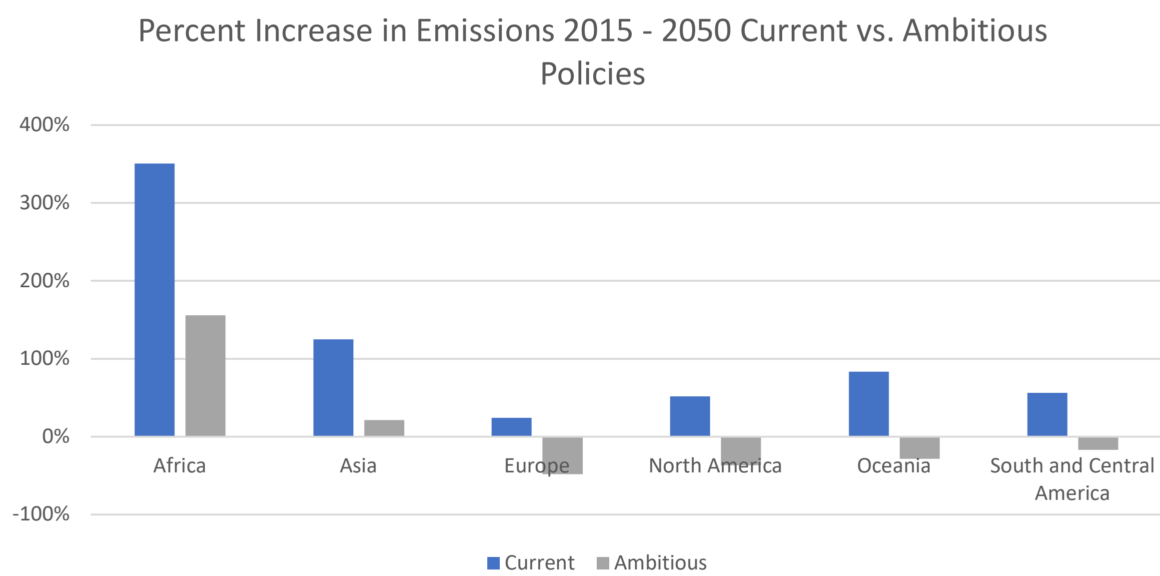

Figure 2:Percent Increase in GHG Emissions (2015 - 2050)

Figure 2 shows the percent change in emissions over time displaying the difference in expected emissions if business continues as usual, as opposed to emissions as a result of imposing highly ambitious transformative regulations, which are currently under consideration. The data shows that given current policies, emissions in all regions will continue to increase in comparison to present emissions. However, by imposing ambitious regulations, emissions will increase only in Asian and African regions. The increase in emissions is attributed to the lack of technological advancements, infrastructure, and increase in freight activities. Although emissions in Asia show the highest carbon emissions in terms of magnitude, the African region presents the highest growth in emissions, and thus a significant opportunity for emission reduction. As such, innovative methods capitalizing on the current transportation network is needed to curb emissions.

3.3.1 Quantifying Carbon Emissions for Transport

Quantifying the carbon avoided, or saved, from the decommissioning of a single diesel truck is the first step for assessing the feasibility of a transportation offset program. This capstone uses standardized methods from the Black Carbon Methodology (Greene, 2017) for black carbon emissions and the GLEC Framework for GHGs (Greene & Lewis, 2019). To evaluate carbon savings, carbon emissions over the operating lifetime of the truck is calculated. A wide range of available standards for emissions calculations are available; however, the most challenging aspect is not in calculation, but in allocating the most appropriate figures to the vehicle and engine type and its operating conditions.

Identifying the various types of trucks and the resulting emissions is the first step in measuring carbon savings. Emissions are calculated in units of carbon dioxide equivalence and black carbon per every ton-kilometer (e.g., black carbon or CO_2e/Ton-kilometer). The study considers carbon intensity factors from freight operations, taking into account the full entire fuel life cycle, from Well-to-Wheel (WTW) (GLEC Framework, 2019). WTW emissions are the fuel life cycle emissions divided into two counterparts, from Well-to-tank (WTT) and from Tank-to-Wheel (TTW). WTT emissions are the fuel emissions from fuel production and all resulting activities until fuel is reserved for storage in tanks. TTW are described as emissions from driving and vary from one engine to another as a result of fuel combustion.

Ton-kilometers for one truck over one year are estimated assuming different activity levels of light, moderate, and heavy, which are used with varying estimates for kilometers travelled, and tonnage carried per year. The study also considers varying average operating years of the vehicles of 7, 11, and 15 years. Table 4 below shows GLEC default values for WTW carbon intensity factors for African truck types running on diesel fuel with their corresponding capacity. GLEC default values are used throughout this capstone to calculate emissions using Scope 3 calculation methods, since actual fuel consumption data in not available. However, if fuel data are available, Scope 1 calculation methods can be used.

Table 4: African Diesel Truck Types and GLEC Default Values

Equipment	Capacity (Tons)	WTW g CO_2e/t-km
Generic Van	4	768
Temperature-control Generic Van	4	1016
Urban Truck	8	451
Temperature-control Urban Truck	8	506
Medium Goods Vehicle	20	244
Temperature-control Medium Goods Vehicle	20	273
Heavy Goods Vehicle	40	126

3.2.2 Scope 1 & Scope 3:

Transport Scope 1 emissions may be measured using a fuel- or energy-based approach, and Scope 3 calculation methods follow an activity-based approach. The method used depends on the data available.

3.2.2.1 Fuel- and Energy-Based Method (Scope 1)

Scope 1 emissions are calculated using an energy-based approach, since actual fuel consumption data is available from purchase receipts and invoices. While this data is not available for purposes of this study, this method is considered more accurate than Scope 3 methods and is calculated by multiplying fuel consumption over the year by the corresponding fuel emissions conversion factors. The equation below shows the calculation methods used for when fuel data is available.

$$\boldsymbol{Kg\ \ CO_2e = \int_1^n fuel\ (Kg)\ \times fuel\ emissions\ factor\ (\frac{Kg\ CO_2e}{Kg\ fuel})}$$

Equation 1: Scope 1 Carbon Emmissions Calculation Method

Fuel emissions factors are used to calculate CO_2e emissions based on the type of energy/fuel combusted. Since fuel consumption data is not available for purposes of this study, an activity-based approach will be used to estimate emissions from transport activities.

3.2.2.2 Activity-Based Method (Scope 3):

An activity-based method is used in cases where fuel data is not available, but information regarding shipment load and distance is, which is the common scenario for scope 3 emissions. An accurate estimate of total ton-kilometer is calculated and multiplied by the corresponding CO_2e intensity factor in Table 4. Ton-kilometer (tkm) is calculated using primary data based on the equation below. For the activity-based approach, CO_2e emissions for freight transport activities are calculated based on two factors, shipment weight and travelled distance. Both factors are combined into and depicted by a ton-kilometers measurement unit, which represents the movement of one ton of load a distance of one kilometer.

$$\boldsymbol{tkm = vehicle\ capacity\ (ton) \times avg\ load\ factor\ \left(\frac{avg\ shipment\ weight\ (ton)}{vehicle\ capacity\ (ton)}\right)}$$
$$\boldsymbol{\times\ total\ distance\ (km) \times loaded\ distance\ factor\ \left(\frac{loaded\ distance\ (km)}{total\ distance\ (km)}\right)}$$

Equation 2: Ton - Kilometer Scope 3 Calculation

The equation above is simplified as follows:

$$\boldsymbol{tkm = total\ weight\ (ton) \times average\ shipment\ distance\ (km)}$$

$$\boldsymbol{Kg\ \ CO_2e = \sum_{1}^{n} total\ tkm\ \times\ CO_2e\ intensity\ factor(\frac{kg\ \ CO_2e}{ton - km})}$$

$$\boldsymbol{Fuel\ or\ \ CO_2e\ intensity\ Factor = \frac{\int_1^n Kg\ fuel\ or\ \ CO_2e}{\int_1^n ton\ \times\ Km}}$$

Equation 3: Simplified Kg CO2e Scope 3 Calculation

Using the previous equations, carbon emissions for the different types of trucks were calculated using GLEC average carbon intensity factors. Figure 3 below shows the carbon emissions in kg CO_2e calculated using Scope 3 calculation methods for one shipment with varying payload and distance. The figure shows the relationship between payload (Ton) and carbon emissions (CO_2e); the larger the payload and the distance traveled, the higher the emissions.

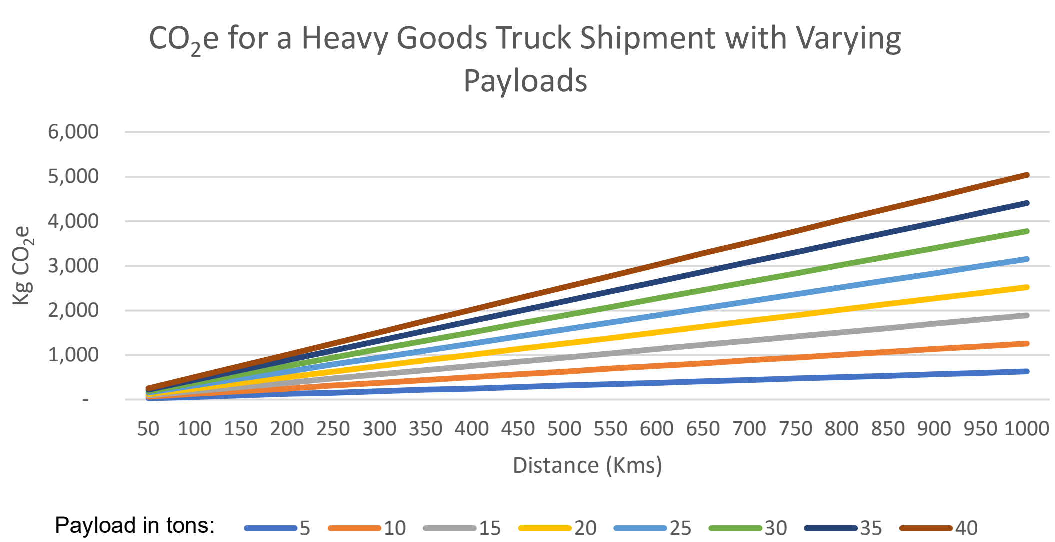

Figure 3: The CO_2e for Heavy Duty Shipments with Varying Distances and Payloads

Building on the previous calculations, CO_2e are calculating incorporating load distance and average load factor in the calculation method. Table 5 below shows the average tons of carbon emissions for a single active heavy-goods truck making five shipments a week for one year with varying load and distance factors. These factors are considered to account for an approximation of the actual utilization of the vehicle, which contributes to the total emissions produced as a result of the vehicle's operation. Based on the average distances collected from Eurostat Road Freight Transport by Journey Characteristics (Eurostat, 2018), the model assumes that the vehicle makes daily 500 km trips for a full year and adopts these values for simplicity.

Table 5: Scope 3 Estimate of Tons CO_2e per Year for a Heavy Goods Truck Operating at Different Activity Levels

Average Load Factor	Loaded Distance Factor									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	7	13	20	26	33	39	46	52	59	66
20%	13	26	39	52	66	79	92	105	118	131
30%	20	39	59	79	98	118	138	157	177	197
40%	26	52	79	105	131	157	183	210	236	262
50%	33	66	98	131	164	197	229	262	295	328
60%	39	79	118	157	197	236	275	314	354	393
70%	46	92	138	183	229	275	321	367	413	459
80%	52	105	157	210	262	314	367	419	472	524
90%	59	118	177	236	295	354	413	472	531	590
100%	66	131	197	262	328	393	459	524	590	655

3.3.2 Black Carbon Calculation

The Black Carbon Methodology for the Logistics Sector offers calculation methods that follow a similar method as the GLEC Framework (Greene, 2017). Black carbon (BC) are small dark particulates that are produced as a result of the incomplete combustion of fuels, as explained in Literature Review. Default values are used to estimate black carbon emissions in units of grams of black carbon per kilometer travelled (g BC / km). The following equation is used to calculate black carbon emissions.

$$\boldsymbol{Black\ Carbon\ (g) = \frac{tonne - kilometer}{payload\ (ton)} \times BC\ emission\ factor\ \left(\frac{black\ carbon\ (g)}{distance\ (km)}\right)}$$

Equation 4: Black Carbon Calculation

BC emissions were calculated for the different vehicle types calculated over a combination of average distances. BC emission factors were collected from the Black Carbon Methodology default factors for black carbon emissions. BC emissions over the one year of operations for a heavy goods truck with the same conditions used to calculated Scope1 and Scope 3 CO_2e emissions were calculated. As shown in Table 6, for example, a heavy goods truck making 260 shipments a year with an average distance of 500 kms emits 26,000 grams of black carbon. The table below shows grams of black carbon emitted for making the 260 shipments at varying distances for one year.

Table 6: BC Emissions in Grams for an Active Heavy Goods Truck That Delivers 260 Shipments a Year

Average Distance Travelled per Shipment (Kms)	g BC
50	2,600
100	5,200
150	7,800
200	10,400
250	13,000
300	15,600
350	18,200
400	20,800
450	23,400
500	26,000
550	28,600
600	31,200
650	33,800
700	36,400

4. Freight Carbon Offset Program Supply & Demand: Results

This section of the capstone provides analyses on the potential demand and market value for a carbon offset program, the emissions avoidance that it could drive, and the funding required to administer such a program.

4.1 Modeling Potential Demand for Freight Carbon Offsets

The scenarios related to global road freight emissions and corporate commitments and existing initiatives were averaged to develop an annual potential market size of 121M metric tons. **Error! Reference source not found.** compares our recommended market size with all calculated scenarios.

Table 7: Estimating Offset Demand Scenario Forecasts (2025)

Scenario Type	Scenario	Carbon offset demand in 2025 (*in million metric Ton CO_2, rounded to the Ton*)
Global Road Freight Carbon Emissions	Scenario 1: Moderate Overall Road Freight %	93
	Scenario 2: Aggressive Overall Road Freight %	*186*
Overall CDP Report Data: Freight or Road Emissions	Scenario 3: Aggressive Offset Agenda: CDP Reporting Companies - Scope 3 (All Freight Method)	*127*
	Scenario 4: Aggressive Offset Agenda: CDP Data - Scope 3 (Road Only)	*1*
Corporate Commitments & Existing Initiatives	Scenario 5: Transport Commitments	*85*
	Scenario 6: 2016 –Transport Carbon Offset Projects	*2*
	Scenario 7: CORSIA Emissions	*166*
Proposed Market Size		***121***

We propose a five-year timeframe for the market to reach our estimated total demand, between 2020 and 2025. This timeframe would allow for market offerings to develop and mature, and for company sustainability commitments to be implemented. We presume a linear growth rate during this five-year time period, before the market reaches its anticipated maturity in 2025.

Error! Reference source not found. illustrates the scenario forecasts, including our proposed market size while **Error! Reference source not found.** illustrates the demand across time, accounting for program scale-up.

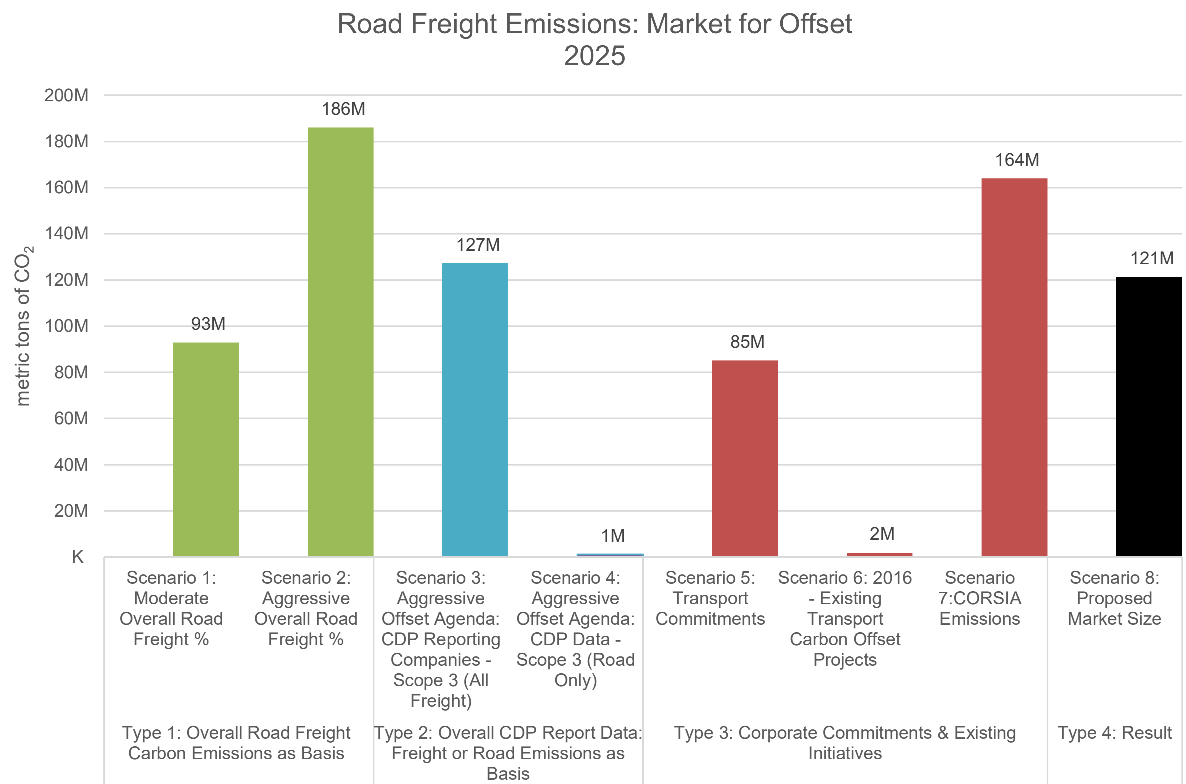

Figure 4: Road Freight Emissions Carbon Offset Market: Scenario Comparison (2025)

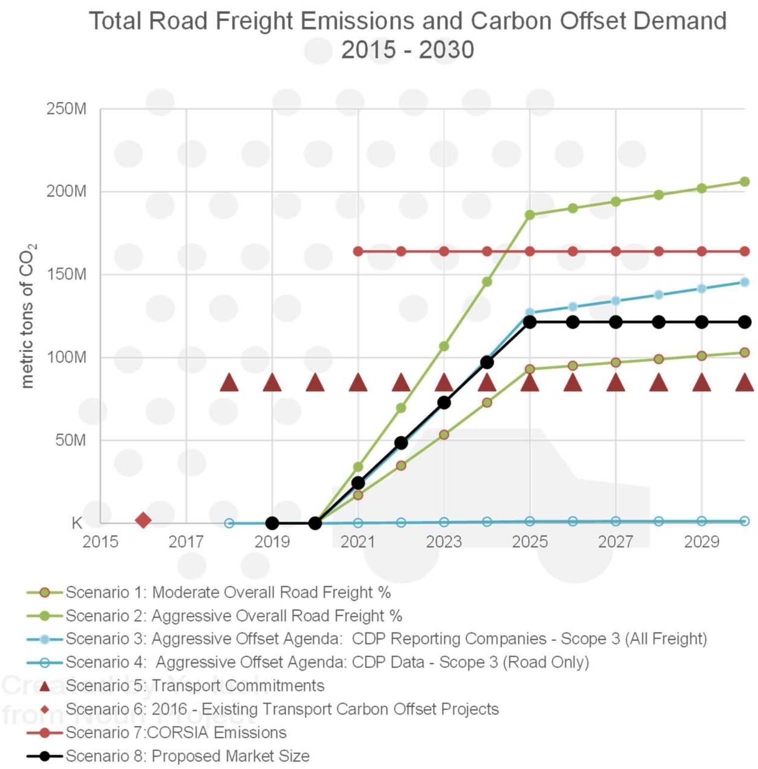

Figure 5: Road Freight Emissions: Carbon Market Offset Market Across Time

4.2 Modeling the Value of Market Demand

We utilized the sample cost ranges illustrated in **Table 3** of \$0.30 to \$11.20 per ton of CO_2 to establish a range of the market value of demand in the global road freight carbon offset market. **Error! Reference source not found.** illustrates this estimated range as between \$36 M and \$1.36B. The current relatively low volume of transportation carbon offset programs available, and the low cost, suggest that the current average transportation carbon offset price may not represent the likely future cost. The CORSIA emissions costs represent a potential maximum estimate, as mandatory carbon emissions programs tend to price carbon at a higher rate than voluntary programs (Hamrick & Gallant, 2018).

Accordingly, we recommend using the average voluntary carbon offset price. Utilizing the average price of carbon in the voluntary offset market estimates the annual demand for road freight emissions offsets to be worth \$364M by 2025.

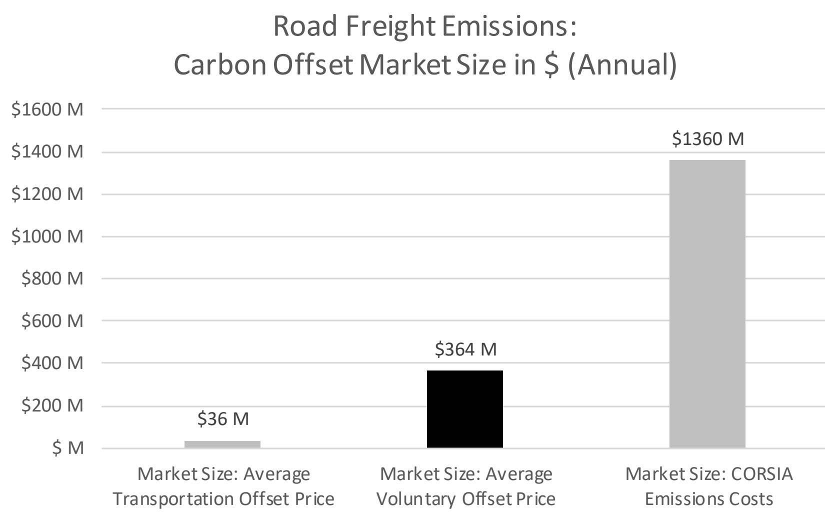

Figure 6: Road Freight Emissions: Carbon Market Offset Size in $

4.3 Carbon Emissions Calculations Results

Carbon emissions (tons CO_2e) and black carbon (g BC) were calculated for the different vehicle types all running under the same conditions over their operating lifetime. Industry defaults for load and distance factors were used for an active fleet (ECTA, 2011). Table 8 below shows the conditions based on which CO_2e and BC emissions were calculated.

Table 8: Average African Active Truck Conditions for 1 Year

# Shipments	260
Operating Years	1
Avg Distance (Km)	500
% Load Factor	85%
% Distance Loaded	75%

Table 9 compares emissions over 1 operating year of active African trucks operating under the same conditions.

Table 9: Emissions for Active Truck Types over 1 Year

Truck Type	Carbon Emissions (Ton CO_2e)	Black Carbon (g BC)
Heavy Goods	418	26,000
Medium Goods	404	15,158
Temp-Control Medium Goods	452	15,158
Urban Truck	299	11,557
Temp-Control Urban Truck	335	11,557
Generic Van	255	11,557

Temp-Control Generic Van	337	11,557

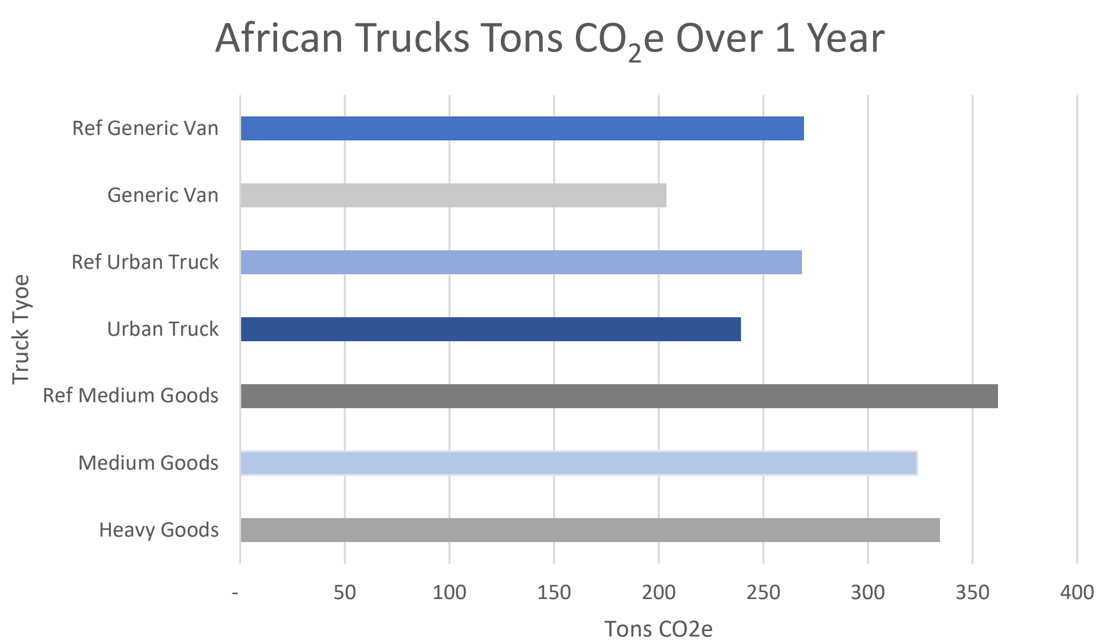

Figure 7: Tons CO_2e For Active African Vehicle Types Over 1 Year

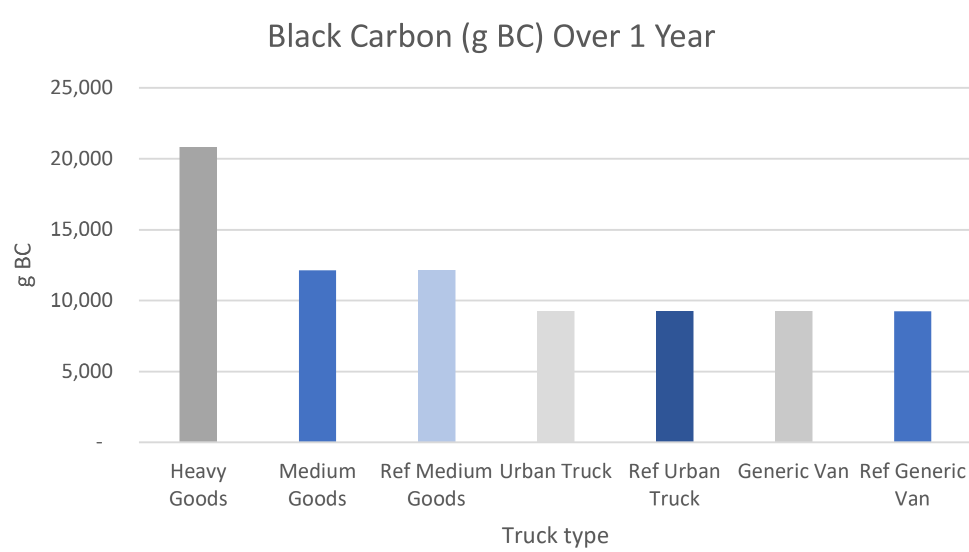

Figure 8: g BC for African Vehicle Types Over 1 Year

Figure 8 above shows a direct relationship between the type of vehicle and the associated black carbon emissions. BC emissions are highest in heavy duty diesel trucks and lowest in light duty vehicles. In regard to CO_2e emissions, the results show that emissions from a temperature-controlled vehicle is much greater than its dry counterpart as a result of the additional energy required for refrigeration. The percentage increase in CO_2e between medium, urban, and generic vehicles is 11%, 12%, and 25% respectively.

4.4 Offset Potential

Modelling the potential market for freight transportation specific carbon offsets is the first step in measuring the expected impact of implementing elimination/renewal programs. By quantifying the demand from purchasing organizations as well as the supply in terms of ton CO_2e for the operating life of different vehicle types, this capstone can quantify the long and short-term effects such programs can have on the environment. Based on a study by the government of Michigan, the operating lifetime of trucks were estimated to have a minimum, maximum, and average value of 7, 15, and 11 years, respectively as shown in Table 10. (Michigan Gov., 2003).

Table 10: Ton CO2e for Active Truck Types Over Operating Lifetime

	Carbon Emissions (Ton CO_2e) of Operating Lifetime		
Truck Type	7 Years	11 Years	15 Years
Heavy Goods	2,924	4,595	6,265
Medium Goods	2,831	4,449	6,066
Ref Medium Goods	3,167	4,977	6,787
Urban Truck	2,093	3,289	4,485
Ref Urban Truck	2,348	3,690	5,032
Generic Van	1,782	2,801	3,819
Ref Generic Van	2,358	3,705	5,052

Table 10 values present tons CO_2e emissions calculated over estimated operating years of active vehicles. After estimating the carbon emissions that a vehicle would emit over its lifetime, an estimate of the potential carbon savings as a result of decommissioning a vehicle is assessed. The program will not buy-back the vehicles for decommissioning until the vehicles approach its end of life. The study assumes the buy-back of the vehicle at different remaining operating years of life as shown in Table 11 below.

Table 11: Potential CO2e Avoided at Purchase Based on Truck Remaining Years of Operation

	Tons CO_2e Avoided at Buy-Back Per Truck Type		
Truck Type	**1 Year**	**3 Years**	**5 Years**
Heavy Goods	418	1,253	2,088
Medium Goods	404	1,213	2,022
Ref Medium Goods	452	1,357	2,262
Urban Truck	299	897	1,495
Ref Urban Truck	335	1,006	1,677
Generic Van	255	764	1,273
Ref Generic Van	337	1,010	1,684

Using the estimated values, this capstone calculates the potential number of African-region-operated vehicles that can be replaced by carbon offsets by dividing ton CO_2e per vehicle by the offset demand market of 120 Million ton CO_2e determined in section 4.1.

After calculating the tons of CO_2e avoided by truck type, shown in Table 11, it is concluded that regardless of the estimated remaining operating years of the vehicle, refrigerated medium goods represent the highest potential CO_2e savings out of the studied vehicle types. However, tons CO_2e avoidance is only one aspect in calculating the best opportunity for buy-back affecting the ultimate cost of carbon credit. Vehicle market value at buyback affects the economic viability of the purchase. This aspect is studied in section 5.3.

4.5 Initial Estimated Costs:

In this section the capstone will estimate the relevant cost factors that constitute the cost of offsetting carbon by employing a fleet decommissioning program.

4.5.1 Cost-Based Method

Since transport carbon offsets would likely occur via the voluntary market, prices could vary widely. Carbon prices in the voluntary market are mainly driven by supply and demand. Using a cost-based method that considers the implementation costs associated with the program ensures the viability and continuity of the project.

While competitiveness in markets drives prices reductions, thus making it easier to reach an objective, it also puts pressure on carbon offset programs to lower their sales prices. Yet, selling carbon credits at prices that are lower than what it costs to maintain operations may halt a project's growth or, even worse, force the project to stop operating. This section will investigate the Gold Standard Fairtrade minimum pricing model and how it can be applied to estimate the costs of a carbon offset fleet decommissioning program. A cost-based pricing model will ensure the continuity of the project and its sustained development.

The equation below estimates the cost of running a fleet renewal program.

$$\boldsymbol{Investment\ Cost + Operations\ Cost + Carbon\ Cost\ - Revenue}$$

Equation 5: Fairtrade Offset Program Cost Calculation

Investment costs pertain to capital investments made in the project, while operations cost include cost to run the project. Carbon offset program costs cover costs for carbon certification, registration, and validation. Relevant costs are added and then revenue is subtracted to provide an overall average cost of ton CO_2e.

4.5.1.1 Certification Costs

Program startup and fixed costs including certification costs and business continuity margin are considered to ensure the sustainability of the program. Certification costs are divided into fixed annual certification fees as well as royalty fees per carbon credit (ton CO_2e). Gold Standard, one of the most trusted certifications in the offset voluntary market, charges a certification fee of $1,500 annually, in addition to a $0.15 per carbon credit.

4.5.1.2 Vehicle Cost

Costs considered are either direct or indirect cost that contribute to the final price of the product, in this case, carbon credit. Cost related to a project include but are not limited to, project initial startup cost. The main cost driver for fleet decommissioning programs is the cost associated with purchasing a vehicle from the operator to incentivize decommissioning and avoid the sale of the vehicle to another freight operator. As discussed in section 4.3.3 Pricing and Incentives, there lies a minimum viable price at which the freight operator is incentivized to decommission a vehicle. This tipping point varies by country, research methods, and truck types.

During calculations, this report considers the vehicle market value (VMV) of the legacy vehicle and provides and an incentive option (I) depending on the program location and truck type.

$$\boldsymbol{VC = VMV \times (1 + I)}$$

Equation 6: Vehicle Cost Equation with Incentives

4.5.1.3 Revenue from Recycling and Scraping (RP)

Upon quantifying the potential for carbon savings from the vehicle as a result of disposal or decommissioning through recycling, an in-depth analysis of decommissioning methods, their costs, and environmental implications is performed. The aim of this section is to conduct a qualitative analysis on vehicle decommissioning and disposal. The vehicles considered for this study are vehicles that are not suitable for engine retrofitting. Vehicle recycling is a complex process as a result of the variety of a vehicle’s components. Although vehicle recycling can result in cost and energy savings over time, it can also lead to the emissions of harmful chemicals if not done in compliance with standards. Typically, vehicle recycling follows a standardized process. Vehicles intended for decommissioning are sent to vehicle recyclers in what is referred to as wrecking yards. All fluids from the vehicle are drained and removed. These fluids include brake fluid, engine and transmission oil, and coolants. Soon after tires, batteries, and converters are removed (State of Washington, 2017).

According to the technology needs assessment report conducted by the United Nations Development Program in accordance with the 2012 climate change report, technology is the main driver for climate mitigation and emissions reductions, accompanied by economic development and growth. It is expected that the number of vehicles reaching their end of life by 2020 to exceed 100 million vehicles (MOE/UNDP, 2015). This means that there is an increasing need to build recycling capacity given the current infrastructure. Recycling efficiency depends on the recycling processes and mechanisms set in place. Recycling process can be categorized into two types, mechanical and manual, with the latter manual process used in developing countries where labor is relatively affordable.

Scrapping facilities value the truck based on its weight. Specifically, the weight of the metals in the vehicle, such as steel, aluminum, copper, and several other sources. These types of metals make up the majority of the truck's weight, more than 55% by weight. For this reason, the selling price for a scrapped heavy-duty truck is higher than that of a generic van. Prices for scrap metals vary from one facility to another based on the processing method used. Prices also vary based on the scrap metal market price.

3.5.1.4 Cost of CO_2e Ton ($/Ton CO_2e)

The cost of one ton of CO_2e is calculated based on the vehicle cost estimated from the previous section after adding an agreed upon incentive to the vehicle market value as illustrated in section 3.5.1.1 and subtracting the revenue that is generated as a result of selling the vehicle for scrap. After calculating the net cost, it is then divided by the total estimated CO_2e saving potential as a result of putting the vehicle out of service. As shown in section 3.4, this value differs from one truck type to another based on its level of activity, operational efficiency as well as its remaining operating years. Below is one instance of the factors taken into consideration while calculating the total carbon saving potential for any of the vehicle types into consideration.

Table 12: Operating Condition Example

Yearly Number of Shipments	260
Remaining Operating Years	5
Avg Trip Distance (Kms)	400
% Load Factor	80%
% Distance Loaded	75%

The unit cost of offsetting one ton of CO_2e through a fleet decommissioning program is calculated by dividing the difference between the Vehicle Cost (VC) and the Recycling Price (RP) and dividing it by the total ton of CO_2e. This calculation is illustrated in the equation below:

$$\boldsymbol{Cost\ Per\ Ton\ CO_2e} = \frac{(\boldsymbol{VC} - \boldsymbol{RP})\ (\$)}{\textbf{Total}\ \boldsymbol{CO_2e}\ \textbf{Savings}\ (\textbf{Ton}\ \boldsymbol{CO_2e})}$$

Equation 7: Cost of Ton CO_2e

To illustrate, an example clarifying a heavy-duty truck assumed to be operating under the same conditions as shown in the Table 12 above is warranted. Market value for the vehicles were obtained from local market websites. A 1995 heavy duty tipper truck in the South African market has an estimated market value of 9000 USD. The estimated vehicle cost after a 10% incentive totals to 9900 USD. The estimated savings in ton of CO_2e is expected to be 1,671 tons CO_2e over an estimated remaining operating lifetime of 5 years. The tipping truck weighs approximately 22 tons. With current scrap prices ranging between the \$60 - \$100 per ton, the truck has an estimated average recycling value (RP) of \$1,760. Using this information as input into the above equation, it is calculated that the cost per ton of CO_2e for this type of truck would be approximately 4.8 \$/Ton CO_2e.

Table 13 below shows the cost of 1 ton of CO_2e for a heavy goods vehicle, operating under the same conditions shown in Table 12 with the same average recycling price of \$1,760. The cost is calculated for a range of vehicle market prices assuming that the operating lifetime of the vehicle is constant at 5 years and does not change with the vehicle market value.

Table 13: Cost of Ton CO_2e for Heavy Goods Vehicle with Varying Market Value

Truck Market Value	\$/Ton
\$ 1,000	\$ (0.395)
\$ 2,000	\$ 0.263
\$ 3,000	\$ 0.922
\$ 4,000	\$ 1.580
\$ 5,000	\$ 2.239
\$ 6,000	\$ 2.897
\$ 7,000	\$ 3.555
\$ 8,000	\$ 4.214
\$ 9,000	\$ 4.872
\$ 10,000	\$ 5.530

5. Limitations and Future Research

5.1 Potential Demand for Freight Carbon Offsets Limitations

The voluntary carbon offset market is highly dynamic. Although it composes less than 5% of the total carbon traded, the voluntary market has grown 50% in size in the last year, and nearly 8-

fold since 2005 (Forest Trends, 2019). It is anticipated to grow further along with growing corporate commitments. It is challenging to forecast such a dynamic market. Our assumption is that the market will continue to grow significantly year over year. If this is not the case, then our anticipated market size for a transportation-related carbon offset program may be too ambitious; or our anticipated market maturity of 2025 may be too soon. We recommend further research in this area, interviewing potential offset customer businesses to gauge their interests. A robust program implementation plan with access to stakeholder interviews may develop a more precise market estimate.

Additional research into this area could consider closely monitoring the size of the voluntary carbon offset market as a whole, interviewing potential offset consumer businesses to gauge their interest in such a program or their strategies for carbon neutrality, and reaching out to existing transportation-related carbon offset programs.

5.2 Modeling the Value of the Market Demand Limitations

As discussed, the market value of carbon offsets is highly variable; with the average transportation carbon offset in the voluntary market and the average price of carbon in the CORSIA program varying by a factor of 30.

Additional research into this area should closely monitor the evolution of the voluntary market offset prices, interviewing potential consumers of the offsets, as well as carbon offset program developers, to better understand a potential market price.

5.3 Carbon Calculations Limitations

The accuracy of carbon emissions calculations depends on the correctness of the input data. While calculating carbon emissions for the different types of vehicles, several assumptions where made. The values used for WTW carbon intensity factors for the different vehicles are standard values for diesel fuel in the African region; however, other factors contribute to the actual carbon emissions, black carbon, and particular matter emitted from the vehicle. These factor are engine type and operating conditions. The study does not take into consideration the engine operating conditions, which may lead to variations from the standard WTW values.

Using primary data of actual fuel consumption (Scope 1) would provide a more accurate representation of the supply as well as the potential for carbon savings. Moreover, carbon emissions savings from vehicle decommissioning greatly depend on the estimated vehicle remaining lifetime and the emissions and costs saving as a result of the remaining operating years (Lin, Chen, & Niemeier, 2007). Two models are available to estimate the probability of truck survival, the Environmental Protection Agency MOBILE 6 model (U.S. Environmental Protection Agency, 2001) and Oak Ridge National Laboratory model (Oak Ridge National Laboratory, 2006). Throughout the calculations conducted, assumptions were made on the remaining operating years of the vehicle. A more accurate representation could have been conducted following the two models stated above. However, this analysis was considered to be out of scope of this study.

6. Fleet Renewal Program Design Recommendations

This section discusses key considerations and best practices in the development of fleet renewal programs and will provide recommendations for our proposed fleet renewal program. **Error! Reference source not found.** illustrates the structure of our discussion.

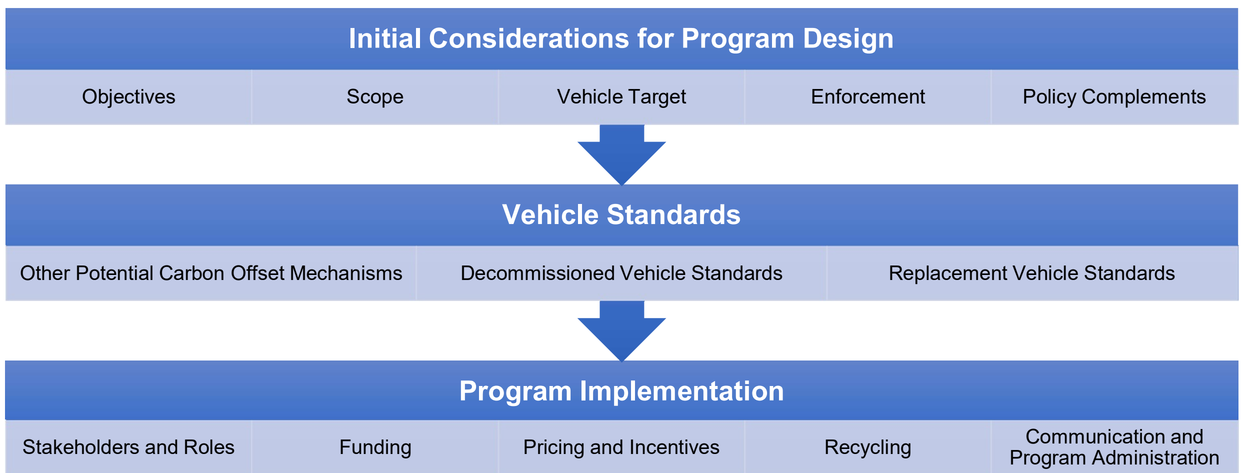

Figure 9: Best Practices in Fleet Renewal Program Design

6.1 Initial Considerations for Program Design

6.1.1 Program Objectives

Fleet renewal programs provide a variety of benefits to individual firms and society. The desired benefits and program objectives should be considered in the design of the program. Some key benefits of fleet renewal programs include:

Environmental: Reduce Emissions. By design, fleet renewal programs decommission high emissions vehicles, leading to avoidance of carbon-based emissions. This has a variety of benefits, including improving air quality and mitigating further acceleration of climate change.

Economic: Support Lower Costs for Businesses. Fleet renewal programs, particularly those targeting commercial or public sector vehicles, often market that decommissioning antiquated vehicles can save organizations and governments in maintenance costs. Lower emissions vehicles tend to be more fuel efficient, leading to decreased future variable costs as well.

Economic: Industry Stimulus. Fleet renewal programs can act as a stimulus package for commerce or the automotive industry. In 2009, the United States launched its Car Allowance Rebate System (CARS) program, commonly known as “cash for clunkers”, in the midst of an economic recession. (Tyson, 2009) The program was able to drive significant increases in purchases of new vehicles.

Political: Road Safety. By design, fleet renewal programs are removing the oldest cars from the road. These vehicles are more likely to have lapsed maintenance needs, break down, or lag in safety technologies. Safety features that have emerged within the past 20 years that may lead to increased road safety include antilock brakes, Electronic Stability Control, airbags, and seatbelt pre-tensioners (International Transport Forum, 2011). Various programs, from Egypt (World Bank, 2020) to the United States, have cited road safety as an incentive for fleet renewal programs. An International Transport Forum analysis estimated that fleet renewal programs in the United States, Germany and France have led to the avoidance of 100+ deaths and 10,000 traffic injuries (International Transport Forum, 2011).

Political: Energy Independence. Fleet renewal programs replace high emissions vehicles with more fuel-efficient alternatives. As a result, past initiatives have cited reducing dependence on imported oil to gain political support for the establishment of large scale fleet renewal program(International Transport Forum, 2011).

Political: Progressive Policy and Income Distribution. In an op-ed advocating for fleet renewal programs, economist Alan Blinder noted that fleet renewals are an example of a progressive policy to distribute funds to lower income individuals, who are more likely to operate older and inefficient vehicles (Blinder, 2008).

Takeaways for Proposed Program*:* Ultimately, the program should be structured with the primary objective in mind. However, additional benefits can be measured and realized, or used to advocate for the establishment of a program. In considering the design of a fleet renewal program funded by carbon offsets, the structure of the program should be designed to drive emissions reductions.

6.1.2 Scope

Fleet renewal programs have been implemented at the national and province/state level, and even in scopes as narrow as a single port. National fleet renewal programs have been conducted in countries as diverse as the United States(Tyson, 2009) , Egypt (World Bank, 2020), Germany, France, Chile, and Mexico(Posada, Francisco; Wagner, David Vance; Bansal, Gaurav; Fernandez, n.d.). Programs are typically operated by the public sector, with eligible grantees being individual citizens, commercial entities, nonprofits, or city/town public sector vehicles.

Takeaways for Proposed Program*:* As of 2020, there were no multinational fleet renewal programs. The proposed program has the potential to be multinational in scope, with funding coming largely from corporate offset purchasers, and targeting vehicles in emerging economies. It may be recommended to initiate a pilot in one country that meets program criteria, and target future expansion.

6.1.3 Vehicle Target

Successful fleet renewal programs have targeted individual passenger vehicles, commercial freight vehicles, commercial operating vehicles, and public transit vehicles such as city buses and school buses. The type of vehicles targeted should be considered in the design and implementation of the program.

Takeaways for Proposed Program: The program will target commercial freight vehicles, largely trucks, as these vehicles contribute disproportionally to emissions.

6.1.4 Enforcement

Fleet renewal programs can be implemented in either a mandatory or voluntary format.

Mandatory Fleet Renewal Programs. There are various channels of enforcement for mandatory fleet renewal programs. Some programs utilize Low Emissions Zones (LEZ); which restrict access to certain urban areas of traffic lanes to vehicles that emit carbon at higher than specified rates. Other programs enforce fleet renewal programs by no longer issuing or renewing permits or licenses to vehicles that exceed certain emissions thresholds. Mandatory fleet renewal programs are run by government organizations and may not require as careful incentive modeling.

Voluntary Fleet Renewal Programs. In contrast to mandatory fleet renewal programs, voluntary fleet renewal programs incentivize vehicle owners to trade in older vehicles. This requires careful program design, with an understanding of stakeholder motivation and decision-making rationale.

Takeaways for Proposed Program*:* The program will operate as a voluntary fleet renewal program.

6.1.5 Policy Complements

For both voluntary and involuntary fleet renewal programs, additional policy compliments can boost the efficacy of the program.

Tax Incentives. On top of the subsidy being offered for the vehicle trade-in, publicly administered programs can utilize tax policy to further incentivize vehicle trade ins or provide tax breaks to individuals or organizations with fuel efficient vehicles.

Proximity to Rules/Regulations. Some fleet renewal programs utilize geographic restrictions to assist in implementation. For instance, the Port of Los Angeles Clean Truck Program ("Port of Los Angeles Clean Truck Program," n.d.) restricted access to the port to vehicles meeting certain emissions standards. Likewise, access to high traffic areas can be limited to trucks with the appropriate registration signifying emissions standards compliance.

Government-Operated Loan Programs. Business owners trading in vehicles to decommission will need to make a capital-intensive purchase for a new vehicle. Although a subsidy for vehicle decommissioning can often partially address this funding need, the purchase of a new vehicle represents a significant financial obligation. Ensuring financing options are available, either through the establishment of public programs or by referrals to private partners, can help address this pain point. The Providing Loan Assistance for California's Equipment (PLACE) is an example of a complimentary loan program that supports investment in fleet renewals. (Posada, Francisco; Wagner, David Vance; Bansal, Gaurav; Fernandez, n.d.)

Takeaways for Proposed Program*:* The program will likely be operated by commercial entities, which may make tax and regulation impact out of scope. However, it is recommended to form partnerships with or establish loan programs to ensure adequate financing is available for freight operators to purchase a new vehicle.

6.2 Vehicle Standards

As noted above in *Vehicle Targets*, fleet renewal programs have been utilized for vehicles ranging from passenger to public sector to commercial vehicles. The program must define the vehicles in scope.

6.2.1 Other Potential Carbon Offset Mechanisms

The decarbonizing mechanism for many fleet renewal programs supports investing in vehicle retrofitting or traditional fleet renewal tactics. There is also the possibility to utilize carbon offsets for other low-carbon transportation-related investments, as described below.

Retrofitting

Retrofitting refers to processes of adding or removing features or components to vehicle's engine to decrease its emissions. Diesel vehicles are often retrofitted by replacing the engine or adding equipment such as a diesel particulate filter to reduce emissions.

One policy advantage of this approach is that it may be relatively low cost in comparison to decommissioning the vehicle and buying a new one. Some fleet renewal programs are based on providing cash for retrofitting.

Vehicle Replacement

Vehicle replacement refers to upgrading an organization's fleet vehicles, by substituting a superior vehicle for legacy vehicles. As part of regular business operations, organizations will intermittently upgrade their fleets to avoid vehicle breakdowns or costly maintenance charges. However, the purchase of a vehicle or vehicles is a capital-intensive investment. Businesses are incentivized to postpone vehicle and fleet upgrades for as long as possible, or even to purchase older, used vehicles. This has led to older vehicles with high emissions continuing to be used. Fleet renewal programs may offer cash for fleet rentals or purchases to replace those vehicles.

In this context, fleet renewal programs do not refer to companies electing to expand their fleet. Instead, it refers to the replacement of vehicles that are currently in use, with vehicles that are superior from an emissions perspective.

Additional investments to support the development of a low carbon freight network

As noted earlier, there are substantial obstacles to the adoption of green freight vehicles, including high costs and a lack of infrastructure (such as charging stations) to support widespread use. Studies have indicated that, In the United States alone, a widespread electric charging network could cost as much as $11B. (Eisenstein, 2019)

In 2016, the United States Department of Justice fined Volkswagen $15B for creating 'defeat devices' to impede emissions measurements for VW vehicles. ("VW Settlement Clearinghouse," n.d.) Much of these funds from the high-profile settlement have gone to support sustainability projects. One initiative born out of this settlement, Electrify America, has led to the creation of electric vehicle charging stations across several US states. (Eisenstein, 2019) Following the Electrify America model, it may be possible to utilize any revenue accrued from a carbon offset network to support the development of this infrastructure, and future investment in electric fleet.

Takeaways for Proposed Program*:*   Our capstone explores the establishment of a traditional vehicle replacement fleet renewal program. A successful fleet renewal program will create effective incentives for business owners, especially small-scale freight operators, to invest in a fleet renewal. Additional decarbonizing standards, such as retrofitting and green vehicle infrastructure development, present interesting opportunities that warrant further consideration.

6.2.2 Decommissioned Vehicle Standards

Within a fleet renewal program, the oldest and highest emission vehicles that are still in continuous operation should be decommissioned, to drive the most significant emissions savings.

Table 14 builds off of work from the Organization for Economic Co-operation and Development (OECD)'s report "Car Fleet Renewal Schemes: Environmental and Safety Impacts" to analyze and simplify various decommissioning vehicle requirements. These represent summaries of decommissioning standards.

As the standards can be complex, it is recommended to cross reference individual program guidelines for in-depth analysis.

Table 14: Selected Fleet Renewal Program Decommissioned Vehicle Standards

Program	Vehicle Type	Decommissioning Standards			
		Fuel Economy	Emissions	Age	Engine Type
CARS – USA (Tyson, 2009)	Passenger Vehicles	18 mpg or less			
Umweltprämie – Germany (International Transport Forum, 2011)	Passenger Vehicles		Euro II or earlier	> 9 years	
Prime à la Casse - France (International Transport Forum, 2011)	Passenger Vehicles			> 10 years	
NYSERDA USA, New York (*New York Truck Voucher Incentive Program*, 2019)	Trucks			> 10 years	Diesel engine
Michigan Clean Diesel Program- 2015 – 2019(*Request for Proposals: Michigan Clean Diesel Program*, 2019)	Buses, Trucks, Non-Road Vehicles			> 9 years	Diesel engine

Another policy design element is ensuring that the vehicle to be decommissioned is currently in use. Programs may require documentation of this, such as inspection, insurance, or odometer records. (Posada et al., 2015)

Takeaways for Proposed Program: To operate effectively, programs must identify clear guidelines for decommissioning vehicle standards. As illustrated above, prior programs have utilized fuel type, age, or emissions standards to identify eligible vehicles. Considering that reliable emissions data may be unavailable or costly to obtain for fleet operators' vehicle in our target geography, the criteria should be flexible, and consider using age or engine type as a proxy.

6.2.3 Vehicle Replacement Standards

To maximize fleet renewal emissions improvement, replacement vehicles should have lower emissions than the vehicles they are replacing. It is critical to have clear standards for replacement vehicles. **Table 15** documents some replacement vehicle standards from prior programs.

Table 15: Selected Fleet Renewal Program Vehicle Replacement Standards

Program	Vehicle Type	Replacement Standards			
		Fuel Economy	Emissions	Age	Engine Type
CARS – USA (Tyson, 2009)	Passenger Vehicles	22 mg			
	Trucks	15 mpg			
Umweltprämie – Germany (International Transport Forum, 2011)	Passenger Vehicles		Euro IV or later standards		
Prime à la Casse - France (International Transport Forum, 2011)	Passenger Vehicles		New car emits < 160 g CO_2/km		
NYSERDA USA, New York (*New York Truck Voucher Incentive Program*, 2019)	Trucks				Electric, hybrid electric, or propane
Michigan Clean Diesel Program- 2015 – 2019(*Request for Proposals: Michigan Clean Diesel Program*, 2019)	Buses, Trucks, Non-Road Vehicles			2016 or newer	

Takeaways for Proposed Program: As with decommissioning vehicle standards, replacement vehicle standards have been defined using age, emissions, fuel efficiency, or engine type. Programs designed to maximize emissions reductions would push for the most stringent replacement vehicle standards. However, the context of the African market and financial position of small-scale freight operators may make the purchase of new vehicles challenging. As such, it's recommended to consider moderate fuel economy or emissions standards that may be present in some used vehicles as a baseline requirement.

6.3 Program Implementation

6.3.1 Stakeholders and Roles

A fleet renewal program is a complex undertaking that requires the engagement of many stakeholders. The below stakeholders should be consulted or informed:

- *Car and Truck Dealerships*. Truck sellers may see an increase in truck demand and/or purchases as a result of the program. It is advisable to inform them in advance of the program, and also of the types of vehicles that are eligible, so they can position themselves to have available inventory. Truck dealerships will also need to participate in a certification process to guarantee that the vehicle being purchased meets the vehicle replacement standards.
- *Scrapping Operators*. Vehicle scrapping operators are likely to see an increase in demand for scrapping services. They will also need to participate in a certification process to guarantee that the legacy vehicle is properly decommissioned.
- *Governments*. Local and national governments should be informed of fleet renewal programs, and consulted regarding their interest in policy complements.
- *Freight Operators*. Freight operators are the primary targeted stakeholder of this type of program. As such, the program should be marketed to them.

6.3.2 Funding

Administering an effective fleet renewal program is costly. Cost drivers for the program include the vehicle subsidies, marketing and communication, administration, and process certification.

Table **16: Select Fleet Renewal Programs' Total Budget** provides an estimate of budgets for several key fleet renewal programs and demonstrates that the budgets can vary widely depending on the program scope and objectives.

Table 16: Select Fleet Renewal Programs' Total Budget

Program	Vehicle Type	Program Budget
CARS – USA (Tyson, 2009)	Passenger Vehicles	$3 Billion USD
Umweltprämie - Germany (International Transport Forum, 2011)	Passenger Vehicles	$7 Billion USD ($5 Billion Euros)
Prime à la Casse - France (International Transport Forum, 2011)	Passenger Vehicles	$600 Million Euros
NYSERDA USA, New York (*New York Truck Voucher Incentive Program*, 2019)	Trucks	$18.4 Million USD
Michigan Clean Diesel Program- 2015 – 2019(*Request for Proposals: Michigan Clean Diesel Program*, 2019)	Buses, Trucks, Non-Road Vehicles	$450 Thousand USD

Of note, many fleet renewal programs in the United States, including those of the states of New York and Michigan, were funded by proceeds from the Volkswagen settlement ("VW Settlement Clearinghouse," n.d.).

This program will be funded by proceeds from a carbon offset program, which we've estimated at $360M annual revenue in **3.2 Modeling the Value of Market Demand** .

6.3.3 Pricing and Incentives

A key element in the design of a fleet renewal program is determining the level of financial incentive required by freight owners to influence them to update their vehicles. Table 17 outlines the funding provided to vehicle purchases for several fleet renewal programs. Most of the programs surveyed either utilized absolute funding amount caps, or designed funding policies.

Table 17: Select Fleet Renewal Programs' Renewal Vehicle Funding Strategy

Program	Vehicle Type	Renewal Vehicle Funding Strategy	
		Funding Amount Specification	Funding Policy Specification
CARS – USA (Tyson, 2009)	Passenger Vehicles	$4500 USD	.
Umweltprämie - Germany (International Transport Forum, 2011)	Passenger Vehicles	$3500 USD	
Prime à la Casse - France (International Transport Forum, 2011)	Passenger Vehicles	$1000 Euros	
NYSERDA USA, New York (*New York Truck Voucher Incentive Program*, 2019)	Trucks	.	95% of difference between diesel and alternative fuel vehicle
Michigan Clean Diesel Program- 2015 – 2019(*Request for Proposals: Michigan Clean Diesel Program*, 2019)	Buses, Trucks, Non-Road Vehicles	.	Up to 25% of new vehicle cost
Carl Moyer Program USA – California. (International Transport Forum, 2011)	Many types	$28,000 USD	

As illustrated, there can be a range of financial support available for new vehicles.

Pricing Theories. There are a variety of considerations when developing the subsidy for fleet renewal programs. Theoretically, the minimum viable incentive for the fleet renewal program is the retail cost of the legacy vehicle; to ensure that decommissioning is more financially attractive than selling the vehicle to another freight operator or selling the engine for scrap. The maximum viable incentive would be the cost of a replacement vehicle.

Many programs aim to reach a ‘tipping point’ (Posada et al., 2015) in providing the minimum amount necessary to incentive freight operator participation, without additional subsidies. Program research into the tipping point has varied depending on the research entity and geographic area of focus. A study suggested that a subsidy of 18% of the new vehicle cost would be required in the United States; while a study in Mexico reported that 70% of the vehicle replacement cost would be necessary to incentivize a fleet renewal (Posada et al., 2015). These differences may be due to research methods, or differences in business operations, the regular rate of fleet upgrades, and access to capital.

Additional Pricing Strategies. Many programs also employ additional pricing strategies in their incentive design. For instance, programs in New York and Michigan provide staggered rates of subsidies, dependent on how optimal/sustainable the replacement vehicle is. Higher rates of support are provided for low-emissions vehicles. The Michigan program also supports retrofitting and will contribute higher relative rates of support for engine renewal support, which is less costly to the program than vehicle purchases.(*Request for Proposals: Michigan Clean Diesel Program*, 2019) The NYSERDA program also provides a unique cost subsidy – supporting the financial difference between purchasing an electric and diesel vehicle. (*New York Truck Voucher Incentive Program*, 2019). Some programs are also designed to provide higher rates of subsidy in the initial years, which decrease over time. This is designed to incentivize freight operators to trade in high-emissions vehicles now, rather than keeping them on the road for another several years (Posada et al., 2015).

Takeaways for Proposed Program. Analyses from the World Bank, referenced in

Table **18** estimates the cost of a new freight vehicle in select areas of Africa to be around $130,000, while a second-hand vehicle may average around $30,000 USD. Considering that fleet renewal programs are less frequent, we would be presuming a ‘tipping point’ of 40% of vehicle costs. This would mean that subsidizing a new vehicle purchase would require on average $50,000, while a used vehicle would require $12,000. Newer vehicles are more likely to be in compliance with emissions standards, so they may be the targeted vehicles.

If this model is pursued, it is recommended to conduct further research on the African freight vehicle market, as available World Bank research is dated. An additional consideration includes the possibility to bulk purchase vehicles in order to drive down prices.

Table 18: Heavy Truck Prices, in USD(Teravaninthorn & Raballand, 2009)

Country	New	Second Hand
Burkina Faso	$ 163,333	$27,000
Ghana	$113,333	$24,688
Uganda	$93,000	$30,690
Kenya	$169,200	$52,144
Zambia	n.a.	$19,613

Table 19: Method of Truck Purchase Financing (Teravaninthorn & Raballand, 2009)

Region	Financed by a bank	Financed by company cash flow	Finance by personal savings	Financed informally
West Africa	21%	58%	47%	8%
Central Africa	34%	42%	46%	13%
East Africa	53%	53%	54%	5%
Southern Africa	7%	56%	56%	11%

Table 19 illustrates the sources of financing for truck purchases in Africa. Most truck purchases are financed by company cash flow or personal savings, while loans from banks are less common. The relative lack of capital support via traditional financial institutions suggests there may be an opportunity to provide attractive loan financing for fleet renewals to support the additional capital required.

6.3.5 Communication and Program Administration

Lastly, it is important to consider an effective communication strategy to ensure that freight operators and the appropriate stakeholders are aware of the program, and that its benefits are clarified. The freight market in much of Africa is decentralized, and composed of small enterprises with relatively few vehicles. (Bove, Hartmann, Stokenberga, Vesin, & Yedan, 2018)

As a result, extra effort must be made to reach out to these stakeholders. Programs in the US have utilized news campaigns and regular webinars to spread awareness. More innovative approaches to reach freight operators may need to be considered, such as outreach in gas stations or partnering with business groups.

7. Conclusions

Rising freight carbon emissions, coupled with increasing corporate interest in climate issues and commitments to decarbonization, present a promising opportunity to develop transport related carbon offset programs. Our capstone found the potential mature carbon offset market demand for transportation carbon offsets to be over 120M metric ton CO_2 per year with an annual value of over $300M, enough to decommission thousands of vehicles. We provided a framework to translate this demand into vehicle decommissioning standards and pricing, and synthesized best practices in fleet renewal practices. An analysis of fleet renewal program best practices provides insights on program design, identifying vehicle standards, and program design, including stakeholders, funding, pricing and incentives, and program administration.

Our hope is that the market size and vehicle analysis along with best practice recommendations will bolster interest in the advancement of such a program in order to drive significant impact in global carbon emissions reduction. Future studies may also explore freight transportation carbon offsets related to projects with a similar objective but different decarbonization mechanism, such as engine retrofitting and electric vehicle charging stations. Interested researchers or implementers may wish engage potential corporate customers in their interest in such a program, engage fleet renewal programs in their targeted geographic area, or conduct stakeholder interviews with small scale freight operators to assess the vehicle marketplace and their interest in such a program.

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