“DECARBONIZATION OF INDIAN ARMY'S TRANSPORT SECTOR: ASSESSING EMISSIONS AND EVALUATING THE APPLICABILITY OF DIFFERENT GREEN TECHNOLOGIES”

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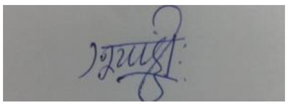
DECLARATION

I, **Pravin Bharat Ubale**, hereby declare that this dissertation entitled 'Decarbonization of Indian Army's Transport Sector: Assessing Emissions and Evaluating the Applicability of Different Green Technologies' is the outcome of my own study undertaken under the guidance of Mr. Kamal Kumar Murari, Assistant Professor and Chairperson, Centre for Environment, Climate Change, and Sustainability Studies, School of Habitat Studies, Tata Institute of Social Sciences, Mumbai.

I declare that this dissertation has been composed solely by myself. It has not previously formed the basis for the award of any degree, diploma, or certificate of this institute. I have duly acknowledged all the sources used by me in the preparation of this dissertation. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission.

Date: 5th April 2023



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CERTIFICATE

This is to certify that the dissertation entitled 'Decarbonization of Indian Army's Transport Sector: Assessing Emissions and Evaluating the Applicability of Different Green Technologies' is the record of the original work done by Mr. Pravin Bharat Ubale under my guidance and supervision. The results of the research presented in this dissertation have not previously formed the basis for the award of any degree, diploma or certificate of this Institute or any other institute or university.

Date: 5th April 2023

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ABSTRACT

This dissertation examines the potential for decarbonizing the transport sector of the Indian Army through the assessment of emissions and the evaluation of various green technologies. The research question focuses on identifying the most effective and efficient path forward for transitioning to a more sustainable transportation system within the Indian military while still meeting operational requirements.

To achieve this, the study employs econometric analysis to estimate the greenhouse gas (GHG) emissions of the Indian military, indicating that the emissions were estimated to be 36.568 MtCO2e, of which stationary emissions were 34.180 MtCO2e, and mobile emissions were 2.387 MtCO2e. The GHG emissions specifically associated with the Indian Army's transport sector were estimated to be 902.4 KtCO2e, providing a baseline for evaluating the potential impact of green technologies.

The study applies Cost Benefits Analysis to analyze the applicability of different green technologies, indicating that electric vehicles are the best option for reducing GHG emissions and meeting sustainability goals within the Indian Army's transport sector. However, based on a range of criteria, including environmental impact, cost, and technical feasibility, hydrogen vehicles are the best options according to the multi-criteria Analysis.

The study provides valuable insights into the potential for decarbonizing the Indian Army's transport sector by assessing emissions and evaluating the applicability of different green technologies. These findings will inform policymakers and military decision-makers on the best path forward for reducing emissions and meeting sustainability goals. The dissertation contributes to the growing body of research on decarbonization of the transport sector and provides a case study for the Indian military that can be applied to other militaries globally.

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Military emissions are becoming increasingly concerning as global emissions continue to rise despite efforts to reduce them. According to Conflict and Environment Observatory (CEOBS) data, military emissions have increased in recent years due to a combination of factors, including increased military activity and continued reliance on fossil fuels for energy production and transportation. This trend highlights the importance of developing effective strategies to reduce short-term and long-term military emissions (Parkinson & Cottrell, 2022). Scientists for Global Responsibility's new report found that the world's militaries are responsible for 5.5% of global greenhouse gas (GHG) emissions, making the military sector the fourth largest contributor to GHG emissions if it were a country with a larger carbon footprint than Russia. The report provides an innovative methodology for estimating global and regional military GHG emissions. It also found that the operational GHG emissions from fuel consumption for military vehicles, aircraft, and ships mainly contribute to global GHG emissions (Parkinson & Cottrell, 2022).

The report provides some interesting comparisons between different countries' military GHG emissions. For instance, the GHG emissions per head of military personnel in the United Kingdom and Germany are 5.0 and 5.1 tons of CO2 equivalent (tCO2e), respectively, while the GHG emissions per head of military personnel in the US are much higher at 12.9 tCO2e (Parkinson & Cottrell, 2022). India's military active personnel was estimated to be around 1458500 personnel (The International Institute for Strategic Studies, 2021, p229), making it one of the largest active military forces in the world. According to the Stockholm International Peace Research Institute (SIPRI), India's military expenditure in 2020 was $72.9 billion[1]. In terms of arms trade, India is one of the largest importers of arms in the world. According to SIPRI, between 2016 and 2020, India was the world's second-largest arms importer after Saudi Arabia, accounting for 9.5% of global arms imports. During this period, India's total arms imports were valued at $17.6 billion[2].

Given the size of India's military, it becomes important to estimate GHG emissions from military operations in order to understand the potential impact on the environment and climate change. Accurate estimates of GHG emissions can help the government to develop strategies to reduce emissions, identify areas for improvement, and ensure that military operations are conducted in an environmentally sustainable manner.

Moreover, the Indian government has committed to reducing its GHG emissions and has set a target of reducing its emissions intensity (GHG emissions per unit of GDP) by 45% by 2030 from 2005 levels, as part of the Paris Agreement on Climate Change (The Press Information Bureau (PIB), 2022). To achieve this target, it is important to include emissions from all sectors, including the military.

Additionally, by estimating GHG emissions from military activities, India can also showcase its leadership and commitment towards climate change mitigation efforts on the global stage, especially in the context of increasing concerns over the impact of climate change on national security.

In summary, estimating GHG emissions from India's military activities is an important step towards reducing emissions, promoting sustainable practices, and achieving the country's climate targets, while also demonstrating leadership and commitment towards climate change

[1] https://milex.sipri.org/sipri

[2] https://armstrade.sipri.org/armstrade/page/values.php

mitigation. Thus, this research attempts to estimate the emissions through the Indian Military and check application of different green technology in the Indian Army.

1.2 Statement of the problem

The transport sector of the Indian Army has been a significant contributor to greenhouse gas emissions, contributing to environmental degradation and climate change. Decarbonization of the Army's transport sector is crucial to mitigating the impacts of climate change and reducing India's carbon footprint. This study aims to assess the emissions generated by the Indian Army's transport sector and evaluate the applicability of different green technologies in reducing carbon emissions.

The problem at hand is twofold. Firstly, the Indian Army's transport sector is a significant contributor to greenhouse gas emissions, which have adverse impacts on the environment and contribute to climate change. The transport sector of the Indian Army is responsible for a significant share of carbon emissions in India, and reducing these emissions is crucial to mitigating climate change. The problem is exacerbated by the fact that the Indian Army relies on fossil fuels, primarily diesel, for its transport needs. This reliance on fossil fuels makes the Army's transport sector a significant contributor to India's carbon footprint.

Secondly, the applicability of different green technologies in reducing carbon emissions from the Indian Army's transport sector is uncertain. While several green technologies, such as electric vehicles, hydrogen fuel cells, and biofuels, are available, their applicability and effectiveness in the Army's unique operational environment are unclear. Moreover, the cost-effectiveness of these green technologies in the Army's transport sector is unknown, and a comprehensive analysis is needed to assess their viability.

Therefore, this study aims to address these two interconnected problems by assessing the carbon emissions generated by the Indian Army's transport sector and evaluating the applicability of different green technologies in reducing these emissions. The study will adopt a quantitative approach to assess the carbon emissions generated by the Army's transport sector, taking into account factors such as the type of vehicle, fuel consumption, and distance traveled. The study will also adopt a quantitative approach to evaluate the applicability of different green technologies in the Army's unique operational environment, taking into account factors such as reliability, maintenance, and cost-effectiveness.

Overall, this study aims to contribute to the ongoing efforts to decarbonize India's transport sector by providing insights into the emissions generated by the Indian Army's transport sector and evaluating the applicability of different green technologies. The study's findings can inform policy decisions and guide the Army's transition towards a more sustainable and environmentally-friendly transport sector.

1.3 Research Aim and Objectives

The aim of the research titled "Decarbonization of Indian Army's Transport Sector: Assessing Emissions and Evaluating the Applicability of Different Green Technologies" is to contribute towards the decarbonization of the Indian Army's transport sector by assessing the carbon emissions generated and evaluating the applicability of different green technologies in reducing these emissions.

To achieve this aim, the research has four specific objectives. The first objective is to estimate the overall greenhouse gas (GHG) emissions of the Indian military. This will provide a baseline for understanding the contribution of the Army's transport sector to the overall GHG emissions of the military.

The second objective is to estimate the GHG emissions generated by the Indian Army's transport sector. This will involve quantifying the emissions generated by various types of vehicles, taking into account factors such as fuel consumption and distance traveled.

The third objective is to analyze the applicability of different green technologies in reducing GHG emissions from the Army's transport sector. This will be done using Cost-Benefit Analysis (CBA) to evaluate the economic viability of different green technologies and identify the most cost-effective solutions.

The fourth objective is to analyze the applicability of different green technologies using Multi-Criteria Analysis (MCA) to evaluate the economic, environmental, and technical feasibility of these technologies. This will provide a comprehensive understanding of the potential benefits and challenges associated with the adoption of different green technologies.

The research aims to provide insights and recommendations for decarbonizing the Indian Army's transport sector through the adoption of green technologies. The research objectives will enable a comprehensive understanding of the GHG emissions generated by the Army's transport sector, the potential benefits and challenges associated with different green technologies, and the most cost-effective and feasible solutions for reducing carbon emissions.

1.4 Significance of the research

The research on decarbonizing the Indian Army's transport sector and evaluating the applicability of different green technologies is significant in several ways. Firstly, the transportation sector is a major contributor to global greenhouse gas emissions, and the military sector is no exception. Therefore, the research is relevant to global efforts towards decarbonization and achieving the goals set forth in the Paris Agreement.

Moreover, the research is significant because it focuses on the Indian Army's transport sector, which is one of the largest consumers of fossil fuels in India. As a country, India has committed to reducing its carbon footprint and transitioning to clean energy sources. The research is essential for achieving India's climate goals and contributing to global efforts to mitigate climate change.

The comparison of the Indian Army's transport sector with the United States military is another significant aspect of the research. The United States military is often considered a leader in adopting green technologies. This comparison provides valuable insights into the potential for adopting similar green technologies in the Indian Army's transport sector and identifies potential challenges and barriers to implementation.

The research addresses a critical need to evaluate the applicability of different green technologies in reducing GHG emissions from the military transport sector. Given the significant contribution of the transportation sector to global emissions, it is crucial to identify and adopt technologies that can reduce emissions without compromising military operations.

Overall, the research on decarbonizing the Indian Army's transport sector and evaluating the applicability of different green technologies is significant in achieving global climate goals, contributing to India's efforts towards decarbonization, and identifying potential solutions for reducing emissions from the military transport sector.

1.5 Limitations of the research

The dissertation "Decarbonization of Indian Army's Transport Sector: Assessing Emissions and Evaluating the Applicability of Different Green Technologies" has few limitations that may affect the accuracy and generalizability of the results. One of the primary limitations is the lack of emission data from larger military countries, which limits the econometric analysis to data from smaller military countries and may inflate the results. Additionally, the cost-benefit analysis and multi-criteria analysis assume that the infrastructure for electric and hydrogen vehicles is already built, which may not reflect the actual situation in India and could affect the accuracy of the results.

The scope of the study is also limited to the transport sector of the Indian Army and does not consider the potential impact of other sectors on the overall carbon footprint of the army. Furthermore, the study may not cover all the possible factors that can affect the decarbonization of the Indian Army's transport sector, such as political and security factors, which could limit the comprehensiveness of the assessment.

Finally, the results of the study may be affected by uncertainties related to the development of new technologies and the availability of renewable energy sources in the future. As a result, while the dissertation provides valuable insights into the decarbonization of the Indian Army's transport sector, it is important to consider these limitations when interpreting the results and making decisions regarding the implementation of green technologies.

1.6 Structure of the dissertation

The structure for the dissertation is organized into ten chapters, each with a specific focus and purpose. Chapter 1 is the introduction, which provides an overview of the research problem, research questions, and the scope of the study. It also describes the importance of the topic and the relevance of the study. Chapter 2 is the literature review, which provides a critical review of existing literature on the decarbonization of military logistics and the use of green technologies in the transport sector. This chapter identifies gaps in the literature and research questions that the study seeks to address. Chapter 3 describes the methodology and data used to estimate the greenhouse gas emissions from the Indian military. It presents the results of the econometric analysis, which estimates the greenhouse gas emissions from the Indian military. Chapter 4 focuses on the current state of logistics in the Indian Army. This estimates emissions from the logistics sector. Chapter 5 proposes different scenarios for the decarbonization of the logistics sector. It discusses the advantages and disadvantages of each scenario. Chapter 6 describes the methodology for cost-benefit analysis of different green technologies in the logistics sector. It presents the results of the cost-benefit analysis. Chapter 7 describes the methodology for multi-criteria analysis of different green technologies in the logistics sector. It presents the results of the multi-criteria analysis

Chapter 8 is the conclusion and future scope, which summarizes the main findings of the study. It discusses the implications of the study for the Indian Army and the logistics sector. It identifies the limitations of the study and suggests directions for future research. Chapter 9 lists all the references cited in the dissertation. Chapter 10 is the appendices, which provides additional details of the data, methodology, and analysis.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Climate Change and Greenhouse Gases

Climate change and greenhouse gas emissions have a strong correlation with one another. As the amount of greenhouse gasses in the atmosphere increases, the Earth's average temperature is rising, leading to a variety of changes in the planet's climate system. The relationship between these two factors can be seen through decades of scientific research and data analysis. (Freebairn, 2020, p3)

Greenhouse gasses, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap heat in the atmosphere, which contributes to global warming. Human activities, such as burning fossil fuels for energy, deforestation, and land use change, have led to a significant increase in the amount of greenhouse gasses in the atmosphere (United States Environmental Protection Agency, 2022).

According to the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), the atmospheric concentrations of CO_2, CH_4, and N_2O have increased by 43%, 148%, and 15% respectively, since 1750. The report also states that the average global temperature has risen by approximately 1.2°C compared to pre-industrial levels, and is projected to rise by 1.5°C to 4.5°C by the end of this century (Intergovernmental Panel on Climate Change, 2021, p14).

The consequences of this rising temperature and increased greenhouse gas concentrations are widespread and far-reaching. Some of the impacts include sea level rise, ocean acidification, loss of Arctic Sea ice, increased frequency and severity of extreme weather events, and the extinction of many plant and animal species.

The AR6 report also highlights that limiting global warming to 1.5°C is still possible, but requires rapid and far-reaching transitions in energy, land use, and infrastructure, as well as changes in societal behavior. Reducing greenhouse gas emissions and transitioning to cleaner forms of energy are key steps in addressing the issue of climate change.

Climate change and greenhouse gas emissions are closely linked, and the continued rise in atmospheric concentrations of these gasses is leading to significant impacts on the planet's climate system. The IPCC's AR6 report underscores the urgency of addressing the issue, and highlights the need for rapid and transformative action. Global military emissions have been a worrying issue in the recent years (Jayaram, 2021, p625).

2.2 Global Military Emissions

The emissions generated by military operations have long been a topic of concern, especially in light of the current global effort to mitigate the impacts of climate change. The military sector is a significant contributor to global greenhouse gas emissions, and understanding the sources and trends of these emissions is crucial for developing effective strategies to reduce them. One way to analyze military emissions is by using the Comprehensive Data on Military Emissions (CEOBS), which provides a comprehensive picture of the military's contribution to global emissions. Unfortunately, emissions data of the Indian military is not available in this database (Conflict and Environment Observatory, 2022).

CEOBS data indicates that military operations result in significant emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are the three most significant greenhouse gasses. The majority of these emissions come from the use of fossil fuels, including diesel and jet fuel, for transportation and energy production. For example, military vehicles and aircraft are major sources of CO_2 emissions, with ground transportation accounting for the largest share. Similarly, military bases and installations rely on large amounts of energy for operations, which contributes to emissions from energy production (Depledge, 2023, p672).

In addition to emissions from energy use, military activities also contribute to emissions through various other processes, including land use changes, waste management practices, and emissions from munitions and other military-related products. For example, military training exercises can result in deforestation and other land use changes, which can have a significant impact on local and regional emissions. Similarly, the use of certain military-related products, such as explosive devices, can result in the release of greenhouse gasses into the atmosphere.

The trend of military emissions is concerning, as global emissions continue to rise, despite efforts to reduce them. According to CEOBS data, military emissions have increased in recent years, driven by a combination of factors, including increased military activity and the continued use of fossil fuels for energy production and transportation. This trend highlights the importance of developing and implementing effective strategies to reduce military emissions, both in the short and long term (Conflict and Environment Observatory, 2022).

One potential strategy for reducing military emissions is to increase the use of renewable energy sources, such as wind, solar, and hydro power. This can help to reduce dependence on fossil fuels and reduce emissions from energy production. In addition, the military can also take steps to reduce emissions from transportation, such as through the use of electric or hybrid vehicles, or by optimizing the use of existing vehicles. Another potential strategy is to improve waste management practices and reduce the use of products that contribute to emissions, such as munitions and other military-related products.

Military operations are a significant contributor to global greenhouse gas emissions, and the trend of these emissions is concerning. To address this issue, it is important to develop and implement effective strategies to reduce military emissions, including increasing the use of renewable energy sources, reducing emissions from transportation, and improving waste management practices. By taking action to reduce military emissions, the military can play a critical role in mitigating the impacts of climate change and advancing global sustainability efforts (Conflict and Environment Observatory, 2020).

The world is facing a major challenge with respect to the rapidly increasing greenhouse gas (GHG) emissions. As the world leaders gather to discuss climate change, it has become increasingly evident that reducing GHG emissions is crucial for mitigating the climate crisis. The 1997 Kyoto Protocol aimed to reduce GHG emissions from industrialized countries by an average of 5% compared to 1990 levels. However, due to pressure from the US, military emissions were excluded from the reporting requirements (Crawford, 2019).

This exclusion has created what is known as the Military Emissions Gap, which has been a major challenge for climate action. Despite the absence of comprehensive data, researchers have made attempts to estimate the scale of the problem through available data. A new report by Scientists for Global Responsibility has found that the world's militaries are responsible for 5.5% of global GHG emissions. This would make the military sector the fourth largest contributor to GHG emissions if it were a country, with a larger carbon footprint than Russia (Conflict and Environment Observatory, 2022).

The report provides an innovative methodology for estimating the global and regional military GHG emissions. Based on available data, the report found that the military sector's operational GHG emissions range from 0.6% to 5.5% of the total global GHG emissions. The operational GHG emissions refer to emissions from fuel consumption for military vehicles, aircraft, and ships (Parkinson, 2022).

The report also provides some comparison between different countries' military GHG emissions. For example, the GHG emissions per head of military personnel in the United

Kingdom and Germany are 5.0- and 5.1-tons CO2 equivalent (tCO2e) respectively. In contrast, the GHG emissions per head of military personnel in the US are much higher at 12.9 tCO2e (Parkinson & Cottrell, 2022).

Region	Leading military nations (ordered by personnel numbers)	Stationary GHG emissions per head (tCO_2e)
North America	USA, Canada	13
Russia and Eurasia	Russia, Ukraine	13
Asia and Oceania	China, India, North Korea, Pakistan, South Korea, Vietnam, Myanmar, Indonesia, Thailand, Sri Lanka, Japan, Australia	9
Middle East and North Africa	Iran, Egypt, Saudi Arabia	9
Europe	Türkiye, France, Germany, Italy, UK	5
Latin America	Brazil, Colombia, Mexico	5
Sub-Saharan Africa	Eritrea, Nigeria, South Africa	2.5

Figures rounded to nearest 0.5 tCO_2e/cap

Figure 1 Stationary GHG emissions per head. Source: Report- "Estimating the Military's Global Greenhouse Gas Emissions" by Scientists for Global responsibility

The Military Emissions Gap continues to be a significant challenge in the fight against climate change. The report by Scientists for Global Responsibility provides important insights into the scale of the problem and highlights the need for comprehensive reporting and action to reduce the military's GHG emissions. The report also provides a baseline for future research and action on the issue and serves as an important reminder that the military sector cannot be ignored in the fight against climate change.

2.3 Global efforts to decarbonize military

The military industry is one of the most significant contributors to these emissions. Therefore, the USA, UK, and other militaries worldwide have taken several initiatives to reduce their GHG emissions. The United States military is one of the largest polluters globally, with the Pentagon consuming more oil than most countries (Lewis, 2021). In 2021, the US Department of Defense (DoD) released its Climate Change Adaptation Roadmap, which outlines strategies for mitigating the impact of climate change on military infrastructure and operations. The DoD also aims to reduce GHG emissions by 34% by 2025, which translates to 41 million metric tons of CO2 emissions annually from the US army (Pennell, 2022). To achieve this, the US military has invested in renewable energy sources such as solar, wind, and geothermal power. Additionally, the US Navy has launched its "Great Green Fleet" initiative (The US Navy, 2016), which aims to reduce its dependence on fossil fuels and transition to biofuels.

Similarly, the United Kingdom's Ministry of Defense (MoD) has taken significant steps to reduce its GHG emissions. In 2019, the UK MoD released its Sustainability and Environmental Management System (SEMS), which outlines the ministry's environmental objectives, including reducing GHG emissions. The SEMS also aims to achieve net-zero carbon emissions by 2050, in line with the UK government's target (Nugee, 2021). The UK MoD has also invested in renewable energy sources, such as wind turbines, solar panels, and biomass boilers. Furthermore, the UK Army has launched the "Sustainable Soldier" program, which encourages soldiers to adopt more sustainable practices in their daily lives.

Other militaries worldwide have also taken initiatives to reduce their GHG emissions. In 2015, the French military launched its "Green Defense" plan, which aims to reduce its carbon footprint by 30% by 2025 (Duro, 2020). The French military has invested in renewable energy sources such as solar panels and wind turbines, and it has also adopted more sustainable practices such as using electric vehicles and energy-efficient buildings. The Swedish Armed Forces have also taken significant steps to reduce their GHG emissions, with the military aiming to reduce its emissions by 60% by 2030 (Vanttinen, 2021). The Swedish military has invested in solar panels, wind turbines, and energy-efficient buildings, among other initiatives. Apart from investing in renewable energy sources, militaries have also adopted more sustainable practices in their day-to-day operations. For example, the UK Army has launched the "Don't Be a Fuel" campaign (Pfeifer, 2021), which encourages soldiers to adopt more sustainable practices such as turning off lights and electronics when not in use. The US military has also adopted more sustainable practices such as reducing its water consumption and using energy-efficient lighting.

The US, UK, and other militaries worldwide have taken significant steps to reduce their GHG emissions. These initiatives include investing in renewable energy sources, adopting more sustainable practices, and setting targets to reduce emissions. While more needs to be done to combat climate change, the efforts of militaries worldwide are commendable and serve as an example for other industries to follow.

2.4 The Indian Military: Overview

The Indian military has been taking significant steps towards reducing greenhouse gas emissions (GHG) and promoting sustainable practices. As a signatory to the Paris Agreement, India has committed to reducing its carbon footprint, and the military has been playing a key role in this effort.

One of the significant initiatives taken by the Indian military is the adoption of renewable energy sources, such as solar power, wind power, and biofuels. The Indian Navy has installed solar panels on its ships and bases (The Indian Navy, 2019), and the Indian Army has been using solar energy to power its forward bases in remote areas (Anand, 2022). The Indian Air Force has also been exploring the use of biofuels to power its aircraft (Press Trust of India, 2022).

Furthermore, the Indian military has been promoting sustainable practices by reducing waste generation, promoting recycling, and adopting eco-friendly technologies. The Indian Army has launched several campaigns to promote waste management, and the Indian Navy has been using bio-toilets on its ships to reduce pollution. The Indian Air Force has been using electric vehicles and has also implemented several measures to reduce its carbon footprint (Press Information Bureau, 2022). These efforts by the Indian military towards reducing GHG emissions are not only beneficial for the environment but also have strategic advantages. The adoption of renewable energy sources makes the military self-sufficient and reduces its dependence on traditional energy sources. It also helps in reducing the vulnerability of the military installations to disruptions in energy supply.

The Indian military has been making significant efforts towards reducing GHG emissions and promoting sustainable practices. These efforts are in line with India's commitment to the Paris Agreement and have strategic advantages. The Indian military's contribution towards reducing GHG emissions is a positive step towards a greener and more sustainable future.

2.5 Significance of Military Decarbonization

The significance of military decarbonization is multifaceted and encompasses environmental, strategic, and economic considerations. From an environmental perspective, military operations have a significant impact on the environment. According to a report by the US Department of Defense, the military is the single largest consumer of energy in the world, and its activities are responsible for a significant portion of global greenhouse gas emissions (Department of Defense USA, 2022). Reducing the carbon footprint of military activities through decarbonization can therefore help mitigate the impact of military operations on the environment.

Strategically, decarbonization can also enhance military readiness and operational effectiveness. In recent years, climate change has emerged as a significant security threat, with rising sea levels, extreme weather events, and other climate-related impacts potentially destabilizing regions and creating humanitarian crises (United Nations, 2023). By reducing its carbon footprint and promoting clean energy technologies, the military can help mitigate the impacts of climate change and improve its ability to respond to these threats.

Finally, from an economic perspective, military decarbonization can help reduce costs and promote innovation. The US military has already begun investing in renewable energy technologies, with solar and wind power becoming increasingly common on military bases (Pennell, 2022). By reducing its reliance on fossil fuels, the military can also reduce its vulnerability to price volatility and supply disruptions.

Military decarbonization is a significant and multifaceted issue with important environmental, strategic, and economic implications. By reducing its carbon footprint and promoting clean energy technologies, the military can help mitigate the impact of its activities on the environment, enhance its strategic readiness, and reduce costs while promoting innovation.

CHAPTER 3

3. ESTIMATION OF GREENHOUSE GASSES EMISSIONS FROM THE INDIAN MILITARY USING ECONOMETRIC ANALYSIS

3.1 Econometric Analysis

India does not release any data on military emissions (Conflict and Environment Observatory, 2022). Thus, it becomes imperative to estimate greenhouse gasses emissions before planning decarbonation strategies. Econometric analysis is a statistical approach used to understand the relationship between economic variables and how they influence each other. It is a critical tool used by economists and policy makers to develop economic models, make predictions, and make informed decisions (Khartit, 2020). Econometrics uses mathematical and statistical techniques to measure and analyze the relationships between variables and to test hypotheses about cause-and-effect relationships.

Econometric analysis starts with collecting data on the variables of interest, and then applying mathematical models to this data in order to analyze the relationships between these variables. The models used in econometrics can be linear or nonlinear, and they may take the form of regression models, time series models, or panel data models, depending on the nature of the data and the research questions being studied.

Once the model is built, econometricians use statistical tests to evaluate the strength and reliability of the relationships between variables. They may also use simulation techniques to test the robustness of their results and to estimate the impact of different economic scenarios on their models.

The results of econometric analysis can have significant implications for economic policy and decision making. For example, by estimating the effects of changes in interest rates or taxes on the economy, econometric analysis can inform policy makers about the potential impact of their decisions on economic growth, inflation, and employment (Taylor & Summers, 2014).

Econometric analysis is a powerful tool that provides valuable insights into the relationships between economic variables and enables policy makers to make informed decisions. As such, it is a critical component of modern economic analysis and decision making, and it is widely used by governments, businesses, and other organizations around the world. In this study, econometric analysis is employed to calculate the greenhouse gas emissions from the Indian military as direct methods such as creating greenhouse gasses inventory is not possible due to data and security constraints.

One example of econometric analysis applied to the military is a study by the Stockholm International Peace Research Institute (SIPRI). The study used econometric models to understand impact on the Human Environment by military activities in over 170 countries. The results showed that military impacts vary greatly between countries and regions, and the researchers concluded that econometric analysis is a valuable tool for estimating the impacts generated by the military sector (Stockholm International Peace Research Institute, 1980).

3.2 Methodology

3.2.1 Defining emissions in the Military

The military sector is one of the largest consumers of energy and is responsible for significant greenhouse gas (GHG) emissions (Lancaster University, 2019). The total military emissions, including both stationary and mobile emissions, are a crucial aspect of understanding the impact of the military on the environment and climate change. The estimation of military emissions has been a challenge due to a lack of data and security concerns. To overcome these challenges, econometric analysis is used to calculate the GHG emissions from the military.

Total Emissions = Stationary Emissions + Mobile Emissions………….. (1)

3.2.2 Stationary Emissions

Stationary emissions refer to the greenhouse gas emissions produced by the military that come from sources that are fixed in place, such as buildings, energy plants, and other infrastructure (Parkinson & Cottrell, 2022). These emissions are a significant contributor to the overall carbon footprint of the military and are an important area of focus in efforts to reduce the military's impact on the environment.

Econometric analysis is often used to calculate the stationary emissions of the military, as direct methods of measurement, such as creating a greenhouse gas inventory, are not feasible due to data and security constraints. In an econometric analysis, stationary emissions are modeled as a function of military expenditure, total military personnel, arms trade, and carbon intensity.

Stationary Emissions = F (e, p, t, c) ....(2)

where

e = military expenditure,
p = total military personnel,
t = arms trade,
c = carbon intensity

Military expenditure is a key driver of stationary emissions, as it is directly related to the military's infrastructure and energy needs. Higher levels of military expenditure are typically associated with larger, more complex infrastructure systems and greater energy consumption, which results in increased greenhouse gas emissions.

Total military personnel also play a role in determining stationary emissions, as a larger military requires more infrastructure to support its operations. This infrastructure, including buildings, energy plants, and other facilities, will contribute to the military's stationary emissions.

The military's arms trade is also a factor in determining stationary emissions, as the production and transport of weapons and military equipment can contribute to emissions. This is particularly true in the case of high-tech weapons systems, which may require large amounts of energy and resources to produce and transport.

Finally, carbon intensity, or the amount of carbon emissions per capita, is an important factor in determining the stationary emissions of the military. In order to reduce its stationary emissions, the military must focus on reducing its carbon intensity by investing in more efficient energy systems and technologies.

Stationary emissions are an important area of focus in efforts to reduce the military's impact on the environment. Through econometric analysis and a focus on factors such as military expenditure, total military personnel, arms trade, and carbon intensity, the military can work to reduce its stationary emissions and help address the challenge of climate change.

3.2.3 Mobile Emissions:

The concept of mobile emissions in the context of the military refers to the greenhouse gas emissions that are produced by vehicles, aircraft, and ships used for military operations. These emissions, which can include carbon dioxide, nitrogen oxides, and other harmful pollutants, contribute to the overall carbon footprint of the military sector. Understanding and quantifying these emissions is critical for assessing the environmental impact of military activities and developing strategies to reduce their environmental impact.

Mobile emissions from the military sector can be significant, as military operations often involve extensive use of transportation and mobile assets. For example, military vehicles, aircraft, and ships are used to transport personnel and equipment, provide logistics support, and conduct operations in various locations around the world (Parkinson & Cottrell, 2022). As a result, the emissions produced by these vehicles and assets can be substantial, and can have a significant impact on local and global air quality, climate change, and other environmental issues.

To accurately quantify mobile emissions from the military sector, a variety of methods can be used. For example, researchers can use fuel consumption data to estimate emissions, or they can use satellite imagery and remote sensing technologies to monitor and measure emissions in real-time. In addition, researchers can use models and simulations to estimate emissions based on various scenarios and assumptions, such as fuel consumption rates, vehicle and aircraft types, and mission profiles. In this study econometric analysis is used to quantify the mobile emissions and given by

Mobile Emissions = F (e, p, t, c) ....(3)

where

e = military expenditure,

p = total military personnel,

t = arms trade,

c = carbon intensity

Given the importance of accurately quantifying mobile emissions from the military sector, there is a growing interest in developing and implementing methods to reduce these emissions. This can include initiatives to improve fuel efficiency, reduce emissions from vehicles and aircraft, and promote the use of alternative fuels and clean energy sources. In addition, there is growing interest in developing strategies to offset emissions through the use of carbon credits, reforestation and other mitigation strategies.

Mobile emissions from the military sector are an important component of the military's overall carbon footprint, and must be accurately quantified and reduced in order to mitigate their impact on the environment and address the challenges posed by climate change.

3.3 Data

3.3.1 Stationary Emissions Data

The Intergovernmental Panel on Climate Change (IPCC) and the Nationally Determined Contributions (NDC) under the Paris Agreement, have established a reporting framework known as Clause 1A5a (Military Emissions Org., 2022) to help nations measure, report, and verify their GHG emissions. This framework covers stationary emissions from the military sector.

The main GHGs that are considered in this framework are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gasses (F-gasses). The purpose of including stationary emissions from the military sector under Clause 1A5a is to provide a comprehensive and accurate assessment of a country's GHG emissions, including those from the military sector, in order to inform and enhance the efforts to mitigate the impacts of climate change. The data collected should be consistent with the internationally accepted methodologies and guidelines provided by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC).

Only very few countries release their stationary emissions but sufficient enough to establish an econometric model. Data for year 2020 is given in the following table:

Country name	Military expenditure, US$ millions[3]	Active personals[4]	Total arms trade in US$[5]	Carbon Intensity (metric tons per capita)[6]	Stationary emissions (as reported under NDC clause 1A5a) MtCO2e[7]
USA	800,672.20	1358500	10,059,000,000	14.67341061	17.52465
Russian Federation	65,907.70	1000000	3,327,428,571	11.79720293	40.72
France	56,647.00	210000	2,140,000,000	4.459547465	1.487
Germany	56,017.03	183638	1,265,000,000	7.911621016	0.374
UK	68,366.40	148220	1,193,000,000	5.220514488	0.9944
Kazakhstan	1,617.79	108740	268,000,000	11.45693783	22.28
Belarus	762.78	62000	36,000,000	6.122237765	1.061
Romania	5,563.30	53000	187,000,000	3.817434477	0.65
Hungary	2,777.13	37650	67,000,000	4.74663103	0.037
Finland	5,903.50	23800	57,000,000	7.372854761	0.949
Norway	8,251.72	23250	522,000,000	6.722269985	0.0001
Slovakia	1,983.21	19500	40,000,000	5.698416255	0.058
Cyprus	517.5	12000	29,000,000	5.851065608	0.022

Table 1 Econometric Data for Stationary Emissions

3.3.2 Mobile Emissions Data

According to the Intergovernmental Panel on Climate Change (IPCC), the NDC (nationally determined contributions) clause 1A5b, reporting of mobile military emissions is necessary for all parties to the UNFCCC. This clause provides guidance on how to measure and report emissions from mobile sources, including those from the military sector.

One of the main challenges in estimating mobile military emissions is the lack of detailed data. Unlike stationary emissions, which can be calculated based on energy consumption, mobile emissions are more difficult to quantify. The IPCC suggests the use of activity data, such as

[3] https://milex.sipri.org/sipri
[4] The military balance 2021
[5] https://armstrade.sipri.org/armstrade/page/values.php
[6] https://data.worldbank.org/indicator/EN.ATM.CO2E.PC
[7] www.militaryemissionsgap.org dataset 2022

fuel consumption, to estimate mobile emissions. However, obtaining accurate and comprehensive data on fuel consumption by military vehicles is a challenge, due to the nature of military operations and the sensitivity of the information.

Despite the challenges, it is important to accurately measure and report mobile military emissions, as they are a significant contributor to GHG emissions. A better understanding of these emissions can help to inform policy decisions, identify areas for improvement, and support the development of effective mitigation strategies. Data on mobile emissions for year 2020 is given in the following table:

Country name	Military expenditure, US$ millions[8]	Active personals[9]	Total arms trade in US$[10]	CO_2 emissions (metric tons per capita)[11]	Mobile emissions (as reported under 1A5b) $MtCO_2e$[12]
United States	800,672.20	1358500	10059000000	14.67341061	16.076
Ukraine	5,942.78	270000	133000000	3.936583531	0.45
Germany	56,017.03	183638	1265000000	7.911621016	0.373
United Kingdom	68,366.40	148220	1193000000	5.220514488	1.419
Greece	8,079.94	142,700	102000000	5.59618907	0.298
Switzerland	5,738.40	140304	189000000	4.359041462	0.119
Spain	19,544.47	133282	1258000000	5.09135092	0.439
Italy	32,006.14	97755	937000000	5.311315442	0.642
Canada	26,449.16	68000	407000000	15.43061283	0.295

[8] https://milex.sipri.org/sipri
[9] The military balance 2021
[10] https://armstrade.sipri.org/armstrade/page/values.php
[11] https://data.worldbank.org/indicator/EN.ATM.CO2E.PC
[12] www.militaryemissionsgap.org dataset 2022

Australia	31,753.72	60330	2054000000	15.25361834	0.947
Denmark	5,391.22	48700	69000000	5.107988509	0.25
Netherlands	13,752.00	41199	1098000000	8.437074627	0.164
Hungary	2,777.13	37650	67000000	4.74663103	0.032
Portugal	4,908.94	27741	93000000	4.339768426	0.067
Belgium	6,311.49	25000	139000000	8.095583954	0.105
Norway	8,251.72	23250	522000000	6.722269985	0.099
Austria	3,825.33	23000	22000000	7.293984252	0.033
Lithuania	1,240.50	23000	211000000	4.198076022	0.028
Slovakia	1,983.21	19500	40000000	5.698416255	0.011
Latvia	826.63	16700	5000000	3.955435862	0.0149
Cyprus	517.5	12000	29000000	5.851065608	0.005
Malta	84.91	1700	8000000	3.293245606	0.004
Luxembourg	460.03	939	85000000	15.30642656	0.0001

Table 2 Econometric Data for Mobile Emissions

3.4 Data Analysis

3.4.1 Econometric Model for Stationary Emissions

The table 3 output is a result of a regression analysis conducted on the data of stationary military emissions reported under IPCC clause 1A5a [table1]. The regression equation models the stationary emissions as a function of military expenditure, number of active military personnel, arms trade, and carbon intensity. The coefficients column provides the estimated values for each of the parameters in the regression equation.

Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-12902.94	4120.56	-3.131	0.01399
Military Expenditure (bn $)	-48.18	30.17	-1.597	0.14891
Active Persons (Thousands)	34.3	12.99	2.64	0.02972
Arms Trade (bn $)	-1065.44	3659.21	-0.291	0.77833
CO2 emissions per capita(tons)	2243.02	632.55	3.546	0.00755

Table 3 Econometric Model for Stationary Emissions

The negative coefficient for military expenditure suggests that a higher military expenditure is associated with a lower stationary emission level. On the other hand, the positive coefficient for the number of active military personnel suggests that a higher number of personnel results in a higher stationary emission level. The negative coefficient for arms trade indicates that a higher arms trade is associated with lower stationary emissions. Finally, the positive coefficient for carbon intensity suggests that a higher carbon intensity results in higher stationary emissions.

The R-squared value of 0.9352 suggests that 93.52% of the variation in stationary emissions can be explained by the four independent variables in the regression equation. The adjusted R-squared of 0.9028 indicates that after adjusting for the number of independent variables, 90.28% of the variation in stationary emissions can still be explained by the regression equation. The F-statistic of 28.86 and the p-value of 8.365e-05 suggest that the regression equation is significant in explaining the variation in stationary emissions.

3.4.2 Econometric Model for Mobile Emissions

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-22.7124	127.079	-0.179	0.86
Military Expenditure (bn $)	18.5886	1.987	9.355	4.08e-08
Active Persons (Thousands)	0.5971	0.8422	0.709	0.488
Arms Trade (bn $)	42.4713	121.055	0.351	0.73
CO2 emissions per capita(tons)	-4.3685	15.1183	-0.289	0.776

Table 4 Econometric Model for Mobile Emissions

The above output [table 4] is a regression result for table 2 the relationship between mobile military emissions and four explanatory variables, which are military expenditure (in billion USD), active personnel (in thousands), arms trade (in billion USD), and CO2 emissions per capita (in metric tons per capita). The regression model uses an ordinary least square method to fit the data and provide estimates of the coefficients of the explanatory variables in the model.

The intercept term, -22.7124, represents the expected value of mobile military emissions when all the explanatory variables have a value of zero. The coefficient for military expenditure, 18.5886, suggests that for each 1 billion USD increase in military expenditure, mobile military emissions are expected to increase by 18.5886 metric tons of CO2 equivalent. The coefficient for active personnel, 0.5971, implies that for every increase of 1000 active personnel, the mobile military emissions are expected to increase by 0.5971 metric tons of CO2 equivalent. The coefficient for arms trade, 42.4713, suggests that for every 1 billion USD increase in arms trade, mobile military emissions are expected to increase by 42.4713 metric tons of CO2 equivalent. Finally, the coefficient for CO2 emissions per capita, -4.3685, indicates that for every increase of 1 metric ton of CO2 emissions per capita, the mobile military emissions are expected to decrease by 4.3685 metric tons of CO2 equivalent.

The multiple R-squared value, 0.9965, indicates that 99.65% of the variance in mobile military emissions can be explained by the variance in the four explanatory variables. The adjusted R-squared value, 0.9957, indicates that 99.57% of the variance in mobile military emissions can be explained by the variance in the four explanatory variables, after adjusting for the number of parameters in the model. The F-statistic, 1211, and its corresponding p-value, < 2.2e-16, indicate that the overall regression model is statistically significant. This means that the explanatory variables in the model can collectively explain the variation in the mobile military emissions.

3. 5 Output - Indian Military Emissions

In 2020, India's military expenditure was $72.9 billion[13], and its active personnel stood at 1458.5[14] thousands, with arms trade amounting to $ 2.95 billion[15]. The country's CO2 emissions per capita were 1.78 metric tons per capita[16]. Using the econometric model, India's greenhouse gas emissions were estimated to be 36.568 MtCO2e, of which stationary emissions were 34.180 MtCO2e and mobile emissions were 2.387 MtCO2e. Table 5 shows the detailed observations on the Indian military's greenhouse gas emissions through econometric model:

India (KtCO2e)	Best Fit	Lower Fit (5%)	Upper Fit (95%)
Stationary Emissions	34180.53	2688.889	65672.16
Mobile Emissions	2387.813	137.266	4638.359
Total Military Emissions	36568.343	2826.155	70310.519

Table 5 Output of Econometric Model

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13 https://milex.sipri.org/sipri
14 The military balance 2021
15 https://armstrade.sipri.org/armstrade/page/values.php
16 https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

Considering per capita emissions, the Army is responsible for the highest amount of GHG emissions, with a total of 31194.88 KtCO2e. The Army also has the largest number of personnel, with 1,237,000 members (The International Institute for Strategic Studies, 2021, p260). In comparison, the Navy has the second-highest GHG emissions, with a total of 1,741.31 KtCO2e, while the Air Force has a total GHG emissions of 3,526.76 KtCO2e.

Overall, the data suggests that the Army is the branch of the military with the highest impact on GHG emissions due to its large number of personnel and associated activities. This highlights the need for the military to explore ways to reduce its carbon footprint and contribute to global efforts to combat climate change.

Branch of Military	GHG Emissions (KtCO2e)	Numbers[17]
Army	31194.88259	1,237,000
Navy	1741.31499	69,050
Air Force	3526.761786	139,850

Table 6 Indian Military composition and emissions

Assuming the Business-as-Usual scenario, that is 25% growth in military expenditure by 2050 (Observer Research Foundation, 2017), Keeping active personnel constant, considering arms trade as 4% of total military expenditure[18] and 3% increase in carbon intensity[19]. The following graph shows the projections of the Indian military emissions in upcoming years.

[17] (The International Institute for Strategic Studies, 2021, p260)
[18] https://armstrade.sipri.org/armstrade/page/values.php
[19] https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

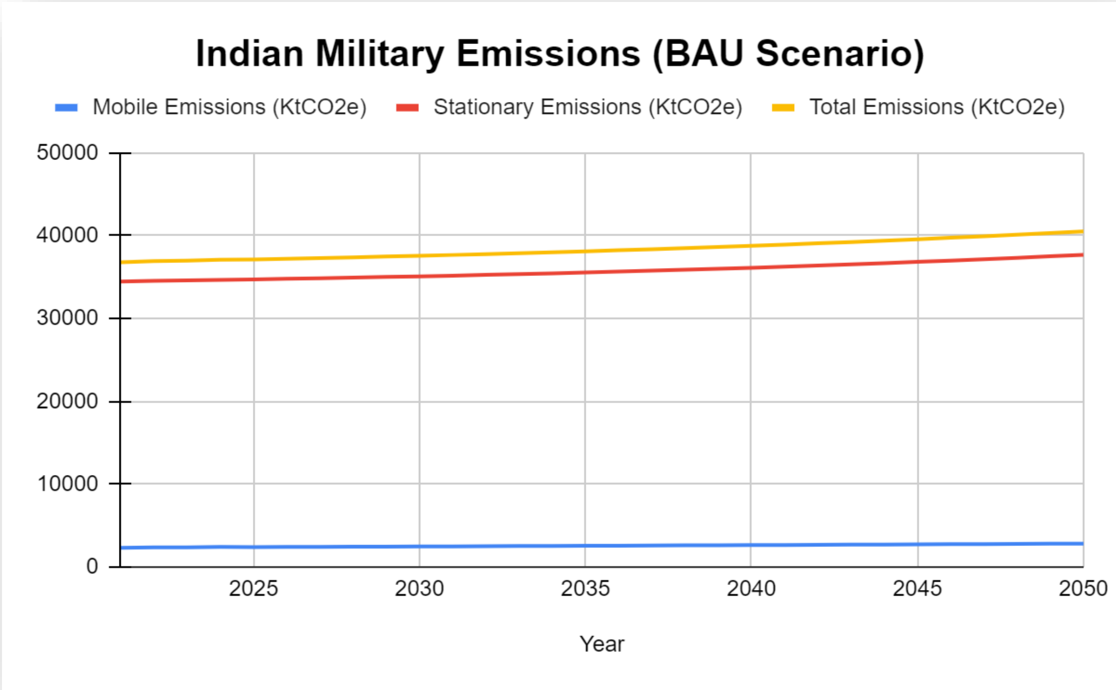

Figure 2 Indian Military Emissions (BAU Scenario)

The data shows that a considerable amount of India's carbon footprint comes from its military sector. Therefore, it is crucial that India takes steps to reduce its military emissions and becomes a leader in sustainable military practices. The government must implement policies and take steps to make the military sector more energy-efficient and environmentally friendly. Moreover, investment in research and development of environmentally friendly technologies, better planning, and management practices can significantly reduce the carbon footprint of the military sector.

The military sector is a significant contributor to a country's carbon footprint and must be taken into consideration while taking steps to combat climate change. India must act quickly to reduce its military emissions and become a leader in sustainable military practices. By doing so, it can not only contribute to the fight against climate change but also set an example for other countries to follow. In the next section, this study analyzes the Indian Army’s logistic sector and its role in reducing greenhouse gas emissions for the Indian Military.

Chapter 4

4. THE INDIAN ARMY: DECARBONIZATION OF LOGISTICS SECTOR

The military is one of the largest consumers of fossil fuels globally and is responsible for significant greenhouse gas (GHG) emissions (Crawford, 2022). The military operations, including transportation, training activities, and stationing of personnel, are significant sources of GHG emissions. According to a report by the CEOBS, military emissions accounted for an estimated around 5% of global emissions in the year 2020 (Conflict and Environment Observatory, 2022). However, the actual emissions are much higher when considering the indirect emissions associated with the production and disposal of military equipment, weapons, and other supplies.

Studies have shown that the military sector has a significant impact on global carbon emissions and climate change (Parkinson & Cottrell, 2022). Military activities consume vast quantities of energy, and the transportation of personnel and equipment is a major contributor to GHG emissions. Additionally, the military’s use of heavy equipment and vehicles, such as tanks, armored vehicles, and aircraft, is another significant source of GHG emissions.

In the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), it is stated that the military sector has the potential to make substantial contributions to mitigating climate change. The IPCC recommends reducing military GHG emissions by increasing energy efficiency and transitioning to low-carbon energy sources.

However, reducing emissions in the military sector is not a straightforward process. The military operates in complex and dynamic environments and requires highly mobile and flexible systems to carry out its mission. As a result, military operations have unique energy requirements that can make reducing emissions challenging.

Despite the challenges, there are several initiatives underway to reduce military emissions. For example, many military organizations are investing in renewable energy sources, such as wind and solar, to power their facilities and reduce their reliance on fossil fuels. The US Department of Defense has also implemented a number of energy-saving measures, such as improving energy efficiency in buildings and vehicles and developing new, more fuel-efficient technologies (Department of Defense USA, 2022).

The military is a significant contributor to global GHG emissions and climate change, and reducing military emissions is an important step in mitigating the effects of climate change. The military logistics sector has the potential to make substantial contributions to mitigating climate change, and there are initiatives underway to reduce emissions in this sector. However, reducing emissions in the military logistics sector is a complex process and requires the development of innovative solutions to meet the unique energy requirements of military operations. The next section gives a brief overview on the logistics sector of the Indian Army.

4.1 Overview of vehicles owned by the Indian Army

The Indian Army's logistics sector plays a vital role in ensuring the mobility and effectiveness of its troops during both peace and war. The army uses a wide range of vehicles for various purposes, including combat, logistics, engineering, and support.

4.1.1 Armored combat vehicles

The armored combat vehicles used by the army include tanks, infantry fighting vehicles, tank destroyers, and armored personnel carriers. The primary battle tank used by the army is the Arjun tank, which is a modern, indigenously developed tank with a 120 mm gun and advanced fire control systems (PIB Delhi, 2021). The BMP-2 "Sarath" is the primary infantry fighting vehicle used by the army. It is a heavily armored vehicle with a 30 mm cannon and can carry up to eight soldiers (Chhina, 2015). The NAMICA is a tank destroyer based on the BMP-2 chassis, and it is armed with four anti-tank guided missiles (Prasad, 2020). The TATA Kestrel is the primary armored personnel carrier used by the army, which can carry up to ten soldiers and is equipped with a 12.7 mm machine gun (PIB, 2022). The NBC Reconnaissance Vehicle is a specialized vehicle used for detecting nuclear, biological, and chemical contamination (DRDO, 2023).

4.1.2 Utility and staff transport

The Indian Army also uses a variety of vehicles for utility and staff transport purposes. The Maruti Gypsy is a light utility vehicle used by the army for various purposes, including patrolling, reconnaissance, and communication (Venugopal, 2020). The Mitsubishi Pajero is used for staff transport purposes and is often used by senior officers. The Polaris Ranger is an all-terrain vehicle that can be used for various tasks, including reconnaissance, patrolling, and transportation (Northlines, 2022).

4.1.3 Goods and field transport vehicles

The Indian Army uses a variety of vehicles for goods and field transport purposes. The DRDO Prahar 510 is a troop carrier that can carry up to 20 soldiers (PTI, 2011). The Tata LPTA 713 TC is a light 4x4 truck that is used for various purposes, including transporting troops, equipment, and supplies (Gershom, 2019). The Tata LPTA 2038 HMV is a medium 6x6 high mobility truck used for transporting heavier loads over difficult terrain. The Ashok Leyland Super Stallion is a heavy 6x6, 8x8, or 10x10 truck used for transporting heavy equipment, ammunition, and supplies (Military Today, 2022).

4.1.4 Engineering and support vehicle

The Indian Army also uses a variety of engineering and support vehicles. The WZT-3M is an armored recovery vehicle used for recovering damaged or disabled armored vehicles. The army also uses other vehicles for engineering and support purposes, including bulldozers, excavators, and bridge-laying vehicles (The International Institute for Strategic Studies, 2021, p267).

Overall, the Indian Army's transport sector is critical to its ability to operate effectively on the battlefield. The army's transport sector is well-equipped and capable of meeting the diverse needs of its troops on the battlefield. The army's vehicles are designed to operate in a variety of terrains, including deserts, mountains, and forests. The army's transport sector is constantly evolving to meet the changing needs of its troops and to keep pace with technological advancements. The Indian Army's transport sector is a key component of its military capability and is essential to its ability to defend the nation's interests.

Vehicle Category	Sub Category	Example
Armored combat vehicles	Tanks	Arjun Tank
	Infantry fighting vehicles	BMP-2 "Sarath"
	Tank destroyers	NAMICA
	Armored personnel carriers	TATA Kestrel
	Miscellaneous vehicles	NBC Reconnaissance Vehicle
Utility and staff transport	Light utility vehicle	Maruti Gypsy
	Staff transport	Mitsubishi Pajero
	All-terrain vehicle	Polaris Ranger

Goods and field transport vehicles	Troop carrier	DRDO Prahar 510
	Light 4x4 truck	Tata LPTA 713 TC
	Medium 6x6 high mobility truck	Tata LPTA 2038 HMV
	Medium/heavy 6x6 8x8 10x10 truck	Ashok Leyland Super Stallion
Engineering and support vehicle	Armored recovery vehicle	WZT-3M

Table 7 Indian Army's vehicle category

4.2 Overview on transport vehicles owned by the Indian Army

The Indian Army's logistics sector plays a crucial role in ensuring the mobility and sustenance of the Indian Armed Forces. The sector encompasses a wide range of activities that includes the transportation of troops, supplies, equipment, and weapons. This sector plays a significant role in the country's military operations and contributes to the Indian Army's effectiveness. However, the sector also contributes to greenhouse gas emissions and plays a role in climate change.

Greenhouse gas emissions from the military sector are a result of the use of fossil fuels in vehicles, ships, and aircraft. The Indian Army's logistics sector primarily operates through diesel-powered vehicles, including AL Stallion 7.5 tons, Tata 2.5 tons, Maruti Gypsy, and supporting machinery like JCBs. These vehicles make up a large portion of the Indian Army's logistics sector. This study focuses on the calculation of greenhouse gas emissions from these diesel-powered vehicles and compares their emissions with possible alternatives.

4.2.1 AL Stallion 7.5 tons Truck

Figure 3 AL Stallion 7.5

The AL Stallion is a 7.5-ton military vehicle used by the Indian Army for logistics and transportation purposes (Ashok Leyland, 2015). With a mileage of 3.5 km per liter of diesel (Reddy & Raghaveni, 2015), it has a carrying capacity of 25 persons and runs an average of 15000 to 100000 km per year (Sun, 2022). The use of diesel fuel by the AL Stallion results in significant greenhouse gas emissions. According to the WRI research, it emits 592.8 grams of carbon dioxide equivalent per kilometer (India GHG Program, 2021). With a total of 70000 vehicles in use (CNBC, 2016). The AL Stallion's heavy reliance on diesel fuel and its significant emissions make it a contributor to climate change. The rise in temperature and the resulting impacts on the environment and human lives are of great concern, and it is essential that steps are taken to reduce the emissions from this vehicle.

One solution could be to switch to alternative fuel sources, such as electric or hydrogen-powered vehicles. The Indian government has implemented policies aimed at promoting the use of electric vehicles and reducing emissions (Aijaz, 2022), but more needs to be done to reduce the impact of the military sector on the environment.

The AL Stallion is an essential component of the Indian Army's logistics sector, but its reliance on diesel fuel and the resulting emissions poses a significant threat to the environment. As climate change continues to be a major concern, it is imperative that steps are taken to reduce the emissions from this vehicle and shift towards more sustainable modes of transportation.

4.3.2 Tata 2.5 tons Truck

Figure 4 Tata 2.5

The Tata 2.5 is a light-duty commercial vehicle manufactured by Tata Motors, one of India's largest automotive manufacturers (Tata, 2016). This vehicle is designed to meet the needs of various industries and businesses, including the Indian Army's logistics sector. With a carrying capacity of 10 people and a fuel efficiency of 4.5 km per liter of diesel (Reddy & Raghaveni, 2015), the Tata 2.5 is a reliable and efficient mode of transportation.

In the Indian Army, the Tata 2.5 is one of the key vehicles used for logistics and support operations. Its compact size and fuel efficiency make it well-suited for transporting supplies and personnel in challenging terrain and remote locations. With an annual average distance covered of 15,000 to 100000 km (Sun, 2022), the Tata 2.5 plays a critical role in keeping the Indian Army's operations running smoothly.

However, despite its many advantages, the Tata 2.5, like other diesel-powered vehicles, contributes to climate change through its greenhouse gas emissions. Diesel vehicles emit nitrogen oxides (NOx), particulate matter (PM), and carbon dioxide (CO2), all of which are harmful to the environment and human health. According to a study, the Tata 2.5 emits 307 gm of CO_2 equivalent per kilometer (India GHG Program, 2021), making it one of the higher emitting vehicles in the Indian Army's logistics sector.

4.3.3 Maruti Gypsy

Figure 5 Maruti Gypsy

Maruti Gypsy is a compact sport utility vehicle (SUV) that has been in production since 1985. It was designed by Suzuki for the Indian market, where it has become a popular choice for military and government use. The Maruti Gypsy is known for its ruggedness and versatility, and is considered to be one of the most capable off-road vehicles in its class (Garg, 2019).

The Maruti Gypsy is powered by a 1.3-liter engine that produces 80 horsepower. It has a top speed of around 120 km/h (Reddy & Raghaveni, 2015), and can cover a distance of up to 15,000 to 100000 km (Sun, 2022) in a year. Despite its small size, the Maruti Gypsy is capable of carrying up to four people and is equipped with a number of features that make it well suited for off-road use, including a high ground clearance, locking differentials, and a low-range transfer case.

The Maruti Gypsy is also considered to be one of the most environmentally friendly vehicles in its class. With a fuel efficiency of 10 km per liter of diesel, it produces relatively low levels of greenhouse gas emissions. This is due in part to its small size and lightweight, which allow it to use less fuel than larger, more powerful vehicles.

However, despite its environmental benefits, the Maruti Gypsy still contributes to climate change through its emissions of carbon dioxide (CO_2). According to data from the datasheet, the Maruti Gypsy produces 204 gm CO_2e per kilometer (India GHG Program, 2021).

4.3.4 Supporting machinery

Figure 6 Supporting Machinery

Supporting machinery is an essential component of the logistics sector in the Indian Army. These machines play a crucial role in supporting various operations of the Indian Army and help to keep the forces moving smoothly. The main function of these machines is to provide support in terms of lifting, moving, and transporting heavy loads. Some of the most common types of supporting machinery used in the Indian Army include JCBs, cranes, and forklifts.

JCBs are widely used in the Indian Army for their versatility and efficiency. They are capable of digging, lifting, and transporting heavy loads, making them ideal for construction work, excavation, and material handling. With their strong and durable design, JCBs are able to withstand the rugged and challenging conditions that are often encountered in military operations. In addition, JCBs are equipped with advanced features such as hydraulic controls, hydraulic braking systems, and powerful engines that make them highly efficient in their tasks. Cranes are also an important type of supporting machinery used in the Indian Army. They are used to lift and move heavy loads such as tanks, vehicles, and ammunition. Cranes are equipped with powerful motors and hydraulic systems that make them capable of handling heavy loads with ease. They are also highly versatile and can be adapted to various types of tasks, making them ideal for use in a wide range of military operations.

Forklifts are another type of supporting machinery used in the Indian Army. They are used to lift and transport heavy loads, making them ideal for use in warehouses, depots, and other storage facilities. Forklifts are equipped with powerful engines, hydraulic systems, and control mechanisms that make them capable of handling heavy loads with ease. They are also highly maneuverable and can be used in tight spaces, making them ideal for use in confined areas.

Following table 8 provides a summary on the vehicles in the Indian Army and its specifications which will be used in the further analysis. This data is for the financial year of 2022. All further calculations are done considering 2022 as the base year.

Table name: Composition of the logistics sector of the Indian Army

Vehicle Type	Numbers	Mileage(km/liter)[20]	Carrying Capacity (Persons)	Minimum annual average distance covered(km)[21]	Fuel (Diesel in liters)
AL Stallion 7.5 tons[22]	70000	3.5	25	15000	4286
Tata 2.5 tons[23]	40000	4.5	10	15000	3333
Maruti Gypsy[24]	31000	10	4	15000	1500
Supporting Machinery[25]	6000	5	1	500	100

Table 8 Overview on military vehicles

[20] (Reddy & Raghaveni, 2015)
[21] (Sun, 2022)
[22] (Ashok Leyland, 2015)
[23] (Tata, 2016)

[24] (Garg, 2019)
[25] Its unit is hours/liter

4.3 Emission Factors

Emission factors play a crucial role in measuring the greenhouse gas (GHG) emissions associated with various activities, including transportation. The emission factor of vehicles is a critical metric that quantifies the amount of GHG emissions released per unit distance traveled. The emission factor is expressed in terms of grams of carbon dioxide equivalent (CO2e) per kilometer (km) or mile. The emission factor of vehicles can be used to estimate the GHG emissions associated with transportation and to evaluate the impact of transportation on climate change.

In the case of vehicles, the emission factor is influenced by several factors such as the type of fuel used, the engine technology, the size and weight of the vehicle, and the driving conditions. In general, the combustion of fossil fuels such as gasoline and diesel produce CO_2, which is the primary GHG associated with transportation emissions. Other GHGs associated with transportation emissions include methane (CH_4) and nitrous oxide (N_2O), which are produced due to incomplete combustion and various other processes (India GHG Program, 2021).

The emission factor of vehicles is influenced by the vehicle's weight and size, the engine's fuel efficiency, and the type of fuel used. Lighter vehicles with smaller engines tend to have lower emission factors than heavier vehicles with larger engines. Similarly, vehicles that use more fuel-efficient engines or alternative fuels such as electric or hybrid vehicles tend to have lower emission factors than vehicles that use conventional gasoline or diesel engines (India GHG Program, 2021).

The emission factor of a vehicle can be calculated using a variety of methods, including laboratory testing and mathematical modeling. In the laboratory, the emission factor is measured by placing the vehicle on a chassis dynamometer and measuring the emissions produced during a standardized driving cycle. Mathematical models, such as the emission factor model (EMFAC) used by the California Air Resources Board, use a variety of data such as vehicle characteristics, driving conditions, and fuel properties to estimate the emission factor of different types of vehicles (California Air Resources Board, 2023).

Vehicle Type	Numbers	CO2e per km (gm)[26]
AL Stallion 7.5 tons	70000	592.8
Tata 2.5 tons	40000	307
Maruti Gypsy	31000	204
Supporting Machinery	6000	300

Table 9 Emission factors

The table 9 above shows the emission factors of various types of vehicles commonly used in the Indian Army. The AL Stallion 7.5-ton truck has an emission factor of 592.8 gm CO2e per km, which is higher than the emission factor of other vehicles such as the Tata 2.5-ton truck and the Maruti Gypsy. These emission factors demonstrate the impact of vehicle weight and engine technology on GHG emissions. The table also shows the emission factors of supporting machinery, which play a significant role in transportation emissions.

The emission factor of vehicles is a critical metric that quantifies the amount of GHG emissions associated with transportation. The emission factor of vehicles is influenced by several factors, including the type of fuel used, the engine technology, the size and weight of the vehicle, and the driving conditions. The emission factor of vehicles can be calculated using a variety of methods, including laboratory testing and mathematical modeling. The emission factors of different types of vehicles demonstrate the impact of vehicle weight, engine technology, and driving conditions on GHG emissions. The emission factor of vehicles is a useful tool for policymakers, researchers, and individuals to evaluate the impact of transportation on climate change and to develop effective strategies to mitigate transportation emissions. Next section focuses on calculating emissions from the logistics sector of the Indian Army using these emission factors.

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[26] (India GHG Program, 2021)

4.4 Data Analysis - Emissions from the Transport Sector

4.4.1 Analysis for Year 2022

The given table presents detailed information on the greenhouse gas (GHG) emissions from different types of vehicles used by the Indian Army's transport sector. The table provides insights into the different vehicle types, their numbers, mileage, minimum and maximum distance covered per year, and their associated GHG emission factors. The emission factors are expressed in grams of carbon dioxide equivalent (CO2e) per kilometer, and the minimum and maximum emissions are calculated in kilotons of CO2e per year.

Vehicle Type	Numbers	Milage (km/liter)	Minimum distance covered per year (km)	Maximum distance covered per year (km)	Emission factor (gm CO2e per Km)	Minimum Emissions CO2e (KtCO2e)	Maximum Emissions CO2e (KtCO2e)
AL Stallion 7.5 tons	70000	3.5	15000	100000	592.8	622.44	4149.60
Tata 2.5	40000	4.5	15000	100000	307	184.20	1228.00
Maruti Jeeps	31000	10	15000	100000	204	94.86	632.40
Supporting Machinery	6000	5	500	2500	300	0.90	4.50

Table 10 Emission range of different vehicles

According to the table 10, the Indian Army's transport sector uses four types of vehicles, including AL Stallion 7.5 tons, Tata 2.5, Maruti Jeeps, and Supporting Machinery, with a total of 151,000 vehicles. The AL Stallion 7.5 tons is the most widely used vehicle, with 70,000 units, while the Supporting Machinery has the lowest number, with 6,000 units.

The mileage column indicates the kilometers traveled by each vehicle per liter of fuel. The AL Stallion 7.5 tons has the lowest mileage, at 3.5 km/liter, while the Maruti Jeeps has the highest mileage, at 10 km/liter.

The emission factor column lists the emission factor of each vehicle type, which takes into account the fuel efficiency of the vehicle and the carbon content of the fuel used. The AL

Stallion 7.5 tons has the highest emission factor, at 592.8 gm CO2e per km, while the Supporting Machinery has the lowest emission factor, at 300 gm CO2e per km.

The minimum and maximum emissions columns provide insight into the GHG emissions produced by each vehicle type per year. The AL Stallion 7.5 tons produces the highest minimum and maximum emissions, at 622.44 KtCO2e and 4,149.60 KtCO2e, respectively, while the Supporting Machinery produces the lowest emissions, at 0.90 KtCO2e and 4.50 KtCO2e.

The Indian Army's transport sector produces a considerable amount of GHG emissions, with a total of 902.40 KtCO2e at the minimum distance covered per year and 6014.50 KtCO2e at the maximum distance covered per year. In short, the Indian Army’s transport sector emits greenhouse gasses in a range of 902.40 KtCO2e to 6014.50 KtCO2e per annum.

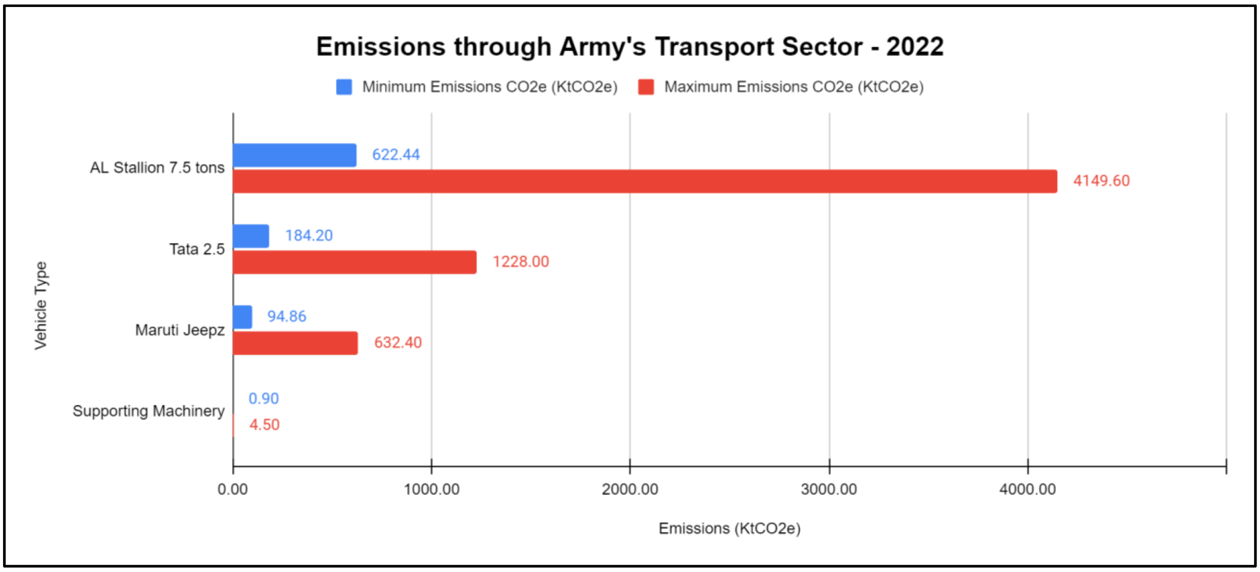

Figure 7 Emissions through Army's transport sector 2022

The graph highlights the urgent need to take measures to reduce GHG emissions from the Indian Army's transport sector. Such measures may include improving the fuel efficiency of the vehicles, promoting the use of alternative fuels, and adopting other eco-friendly practices.

4.4.2 Emissions by 2050 (BAU Scenario)

The analysis shows the estimated minimum and maximum emissions of carbon dioxide equivalents (CO2e) by the Indian Army's transportation sector by 2050 under a business-as-usual (BAU) scenario where the focus is on maintenance of the existing fleet rather than increasing the number of vehicles (Observer Research Foundation, 2017).

This analysis shows that for all the years mentioned, the minimum and maximum emissions are the same as in the previous table, i.e., 902.4 KtCO2e to 6014.5 KtCO2e. According to the Business-As-Usual (BAU) scenario, the total cumulative emissions will be in the range of 26,169.6 (KtCO2e) to 174,420.5 (KtCO2e) by the end of 2050. This indicates that even with the focus on upgrading the transport sector, the overall emissions from the Indian Army's transportation activities are not expected to decrease significantly in the coming decades.

However, it is important to note that upgrading the existing fleet can result in some efficiency improvements and emission reductions compared to continuing with the current fleet. Additionally, the actual emissions in the future will depend on various factors, including the pace of technological advancements, changes in military operations and fuel prices, and the adoption of alternative fuels and energy sources.

Therefore, while the graph 7 provides a baseline for assessing the potential emissions from the Indian Army's transport sector, it should be viewed as an estimation, and efforts should continue to be made to reduce emissions through various strategies and innovations. The graph provided highlights the greenhouse gas emissions produced by different vehicles and supporting machinery over thirty different years. The data indicates that the Al Stallion 7.5 is the most significant contributor to emissions throughout the years, and the total emissions will continue to increase if no further action is taken. Therefore, it is essential to adopt effective measures to reduce greenhouse gas emissions and address the adverse effects of climate change. Next chapter analyzes the role of green technologies such as electric vehicles and hydrogen fuel in reducing emissions.

Chapter 5

5. GREEN SCENARIOS FOR THE LOGISTICS SECTOR

As the world continues to grapple with the challenges of climate change and the depletion of fossil fuels, the transportation sector has emerged as a critical area for transformation. While traditional petrol and diesel vehicles have been the norm for decades, alternative power sources such as electric and hydrogen are rapidly gaining traction. With this shift, there is a growing need for scenario analysis to help policymakers, businesses, and individuals make informed decisions about the future of transportation. Scenario analysis involves the creation of plausible future scenarios that can help stakeholders understand the potential in greenhouse gasses reduction. In this context, scenario analysis can be a powerful tool for evaluating the potential benefits and drawbacks of diesel, electric, and hydrogen vehicles, and for informing the development of effective policies to promote their adoption. This introduction sets the stage for a deeper exploration of how scenario analysis can help to study emissions through the future of transportation, and how it can be applied specifically to diesel, electric, and hydrogen vehicles.

The current greener options available for the Indian Army are total upgradation to Bharat Stage VI, Electric, Hybrid or Hydrogen engines from current Bharat Stage III engines. Next section provides an overview of the different types of engines.

Scenarios	Engines
1	BAU: Bharat Stage 3
2	Upgrading all vehicles to Bharat Stage 6
3	Upgrading all vehicles to Hybrid mode
4	Upgrading all vehicles to Electric mode
5	Upgrading all vehicles to Hydrogen mode

Table 11 Green Scenarios

5.1 Bharat Stage VI Vehicles

Bharat Stage (BS) 6 vehicles are the latest generation of vehicles designed to comply with the stringent emissions norms laid down by the Indian government, while Bharat Stage 3 (BS3) vehicles were designed to comply with earlier, less stringent norms. One of the key areas in which these two generations of vehicles differ is in their greenhouse gas (GHG) emissions. This section compares the GHG emissions of BS6 and BS3 vehicles and examines the impact of this difference on the environment.

To understand the difference in GHG emissions between BS6 and BS3 vehicles, it is important to first understand the differences between the two standards. The BS6 standard was introduced in April 2020, and mandates the use of advanced technology such as particulate filters, selective catalytic reduction (SCR), and on-board diagnostics (OBD) to reduce emissions of nitrogen oxides (NOx), particulate matter (PM), and other harmful pollutants. In contrast, the BS3 standard, which was introduced in 2010, required only the use of fuel injection systems and oxidation catalysts to reduce emissions (Sathiamoorthy et al., 2021).

The use of advanced technology in BS6 vehicles has significantly reduced their GHG emissions compared to BS3 vehicles. According to a study conducted by the International Council on Clean Transportation (ICCT), BS6 vehicles emit 25-30% less carbon dioxide (CO2) than their

BS3 counterparts (Sathiamoorthy et al., 2021). This is due to a combination of factors, including more efficient combustion, improved fuel injection systems, and the use of SCR technology to reduce NOx emissions, which in turn reduces the production of secondary pollutants such as ozone.

Reducing GHG emissions is crucial to mitigating the impact of climate change, and the difference in emissions between BS6 and BS3 vehicles is significant. The reduction in GHG emissions from BS6 vehicles is likely to have a positive impact on air quality, as well as on human health. Exposure to high levels of GHG emissions has been linked to a range of health problems, including respiratory and cardiovascular diseases, and reducing these emissions is therefore a priority for policymakers.

The comparison between BS6 and BS3 vehicles shows that the former emits significantly less GHGs than the latter. This is due to the use of advanced technology in BS6 vehicles, which reduces emissions of NOx, PM, and other pollutants. The reduction in GHG emissions from BS6 vehicles is likely to have a positive impact on air quality, as well as on human health. As a result, the shift towards BS6 vehicles is an important step towards a cleaner, more sustainable future for India.

5.2 Hybrid vehicles

Hybrid vehicles and Bharat Stage 3 (BS3) vehicles are two different types of vehicles with varying levels of greenhouse gas (GHG) emissions. While BS3 vehicles are traditional petrol or diesel-powered vehicles that were designed to meet earlier, less stringent emissions norms, hybrid vehicles use a combination of an internal combustion engine and an electric motor to reduce emissions. This section compares the GHG emissions of hybrid vehicles and BS3 vehicles and examines the impact of this difference on the environment.

Hybrid vehicles have been gaining popularity in recent years due to their lower emissions compared to traditional gasoline or diesel-powered vehicles. Hybrid vehicles use a combination of an internal combustion engine and an electric motor, which reduces the amount of fuel that is burned and therefore reduces emissions of CO2 and other GHGs. The specific amount of GHG emissions from hybrid vehicles varies depending on the type of hybrid technology used, but in general, hybrid vehicles emit significantly less GHGs than traditional vehicles.

In contrast, BS3 vehicles were designed to comply with earlier, less stringent emissions norms, and as a result, they emit higher levels of GHGs than hybrid vehicles. According to a study conducted by the International Council on Clean Transportation (ICCT), hybrid vehicles emit 30-35% less carbon dioxide (CO2) than their BS3 counterparts (Dornof, 2021). This represents a significant difference in GHG emissions between the two types of vehicles.

Reducing GHG emissions is crucial to mitigating the impact of climate change, and the difference in emissions between hybrid vehicles and BS3 vehicles is significant. The reduction in GHG emissions from hybrid vehicles is likely to have a positive impact on air quality, as well as on human health. The comparison between hybrid vehicles and BS3 vehicles shows that hybrid vehicles emit significantly less GHGs than BS3 vehicles. This is due to the use of hybrid technology, which reduces the amount of fuel that is burned and therefore reduces emissions of CO2 and other GHGs. The reduction in GHG emissions from hybrid vehicles is likely to have a positive impact on air quality, as well as on human health. As a result, the shift towards hybrid vehicles is a viable option for the Indian Army.

5.3 Electric Vehicles

Electric vehicles (EVs) and Bharat Stage 3 (BS3) vehicles are two very different types of vehicles with vastly different levels of greenhouse gas (GHG) emissions. BS3 vehicles are traditional petrol or diesel-powered vehicles designed to comply with earlier, less stringent emissions norms, while EVs use electricity to power an electric motor, and emit zero tailpipe emissions. This section compares the GHG emissions of EVs and BS3 vehicles and examines the impact of this difference on the environment.

EVs are often touted as the cleanest vehicles available due to their zero tailpipe emissions. This means that they emit no GHGs during use, and the only GHGs produced during their lifecycle are associated with the generation of the electricity that they use. According to a study conducted by the international energy agency, electric vehicles emit 45-50% less carbon dioxide (CO2) than their BS3 counterparts (IEA, 2022).

BS3 vehicles, on the other hand, emit significantly more GHGs than EVs due to the combustion of gasoline or diesel fuel. These vehicles produce emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which contribute to the formation of smog and other air pollutants (IEA, 2022). The emissions of these pollutants have been linked to a range of health problems, including respiratory and cardiovascular diseases.

Reducing GHG emissions is crucial to mitigating the impact of climate change, and the difference in emissions between EVs and BS3 vehicles is significant. The shift towards EVs is an important step towards reducing GHG emissions and promoting a cleaner, more sustainable future. The comparison between EVs and BS3 vehicles shows that EVs emit significantly less GHGs than BS3 vehicles. This is due to the use of electric motors, which do not produce emissions during use. As a result, the shift towards EVs is an important step towards a cleaner, more sustainable future for India.

5.4 Hydrogen Vehicles

Hydrogen vehicles and Bharat Stage 3 (BS3) vehicles are two very different types of vehicles with vastly different levels of greenhouse gas (GHG) emissions. BS3 vehicles are traditional petrol or diesel-powered vehicles designed to comply with earlier, less stringent emissions norms, while hydrogen vehicles use hydrogen fuel cells to power an electric motor, and emit zero tailpipe emissions. In this section, the study will compare the GHG emissions of hydrogen vehicles and BS3 vehicles and examine the impact of this difference on the environment.

Hydrogen vehicles are often touted as a clean alternative to traditional gasoline and diesel vehicles due to their zero tailpipe emissions. Hydrogen fuel cells use hydrogen gas to produce electricity to power the vehicle's electric motor, which means that the only emission produced during use is water vapor. According to a study conducted by the International Council on Clean Transportation (ICCT), hydrogen vehicles emit 75-80% less carbon dioxide (CO_2) than their BS3 counterparts (Basma & Rodríguez, 2022).

BS3 vehicles, on the other hand, emit significantly more GHGs than hydrogen vehicles due to the combustion of gasoline or diesel fuel. These vehicles produce emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x), which contribute to the formation of smog and other air pollutants. The emissions of these pollutants have been linked to a range of health problems, including respiratory and cardiovascular diseases.

Reducing GHG emissions is crucial to mitigating the impact of climate change, and the difference in emissions between hydrogen vehicles and BS3 vehicles is significant. The shift towards hydrogen vehicles is an important step towards reducing GHG emissions and promoting a cleaner, more sustainable future. The comparison between hydrogen vehicles and BS3 vehicles shows that hydrogen vehicles emit significantly less GHGs than BS3 vehicles. This is due to the use of hydrogen fuel cells, which do not produce emissions during use. The reduction in GHG emissions from hydrogen vehicles is likely to have a positive impact on air quality. As a result, the shift towards hydrogen vehicles is an important step towards a cleaner, more sustainable future for the Indian Army.

5.5 Comparative analysis of emissions from the different scenarios

The scenario analysis of emissions in the Indian Army reveals a significant difference in the amount of greenhouse gas emissions among various types of vehicles. The figure 10 shows the comparison between emissions of Bharat Stage 3 (BS3) vehicles, Bharat Stage 6 (BS6) vehicles, hybrid electric and diesel vehicles, electric vehicles (EVs), and hydrogen fuel vehicles for the year 2022.

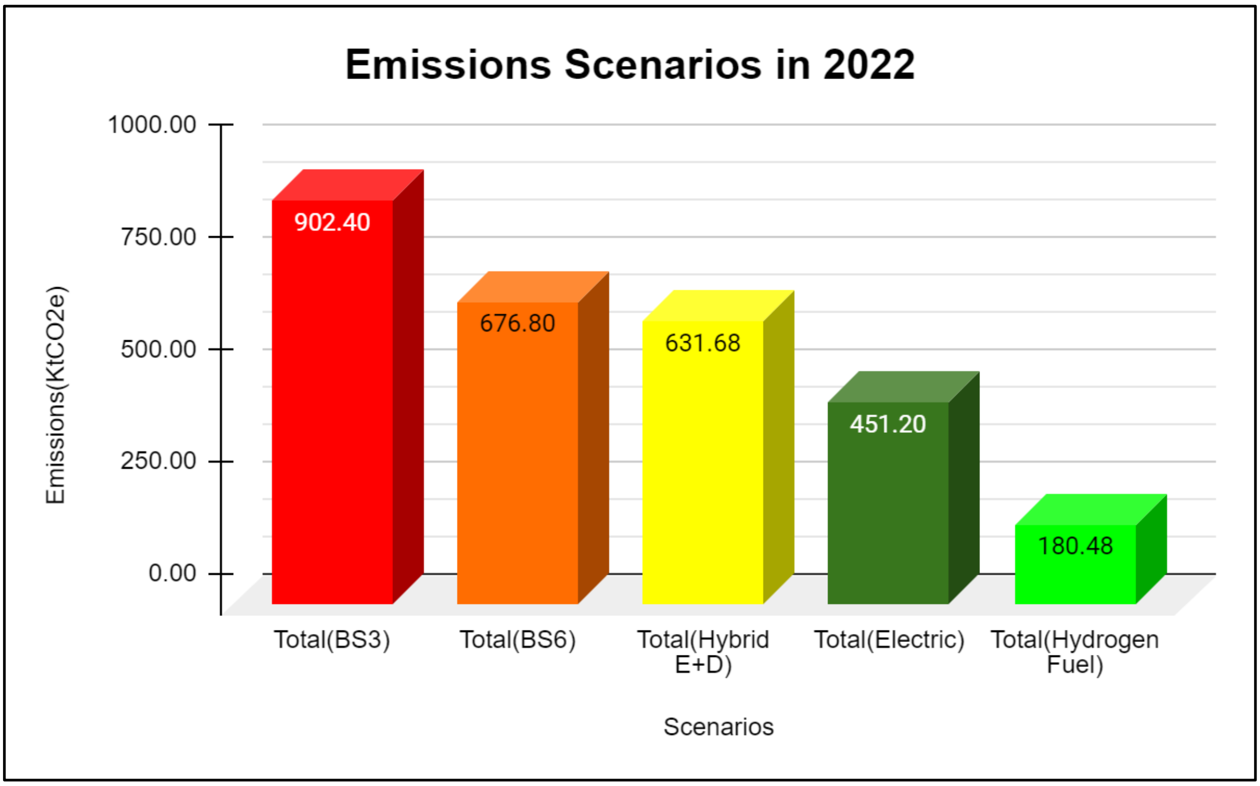

Figure 8 Analysis: Emissions comparison of different scenarios

The data clearly indicates that the transition to cleaner vehicles has a considerable impact on reducing greenhouse gas emissions. The total emissions from BS3 vehicles were 902.40 KtCO2e, while the total emissions from BS6 vehicles, which are more advanced and environmentally friendly, were reduced to 676.80 KtCO2e. The difference between the two emissions levels is significant and highlights the importance of transitioning to cleaner vehicles.

Hybrid electric and diesel vehicles were found to have even lower emissions than BS6 vehicles, with a total emission of 631.68 KtCO2e. These vehicles combine an electric motor with a traditional internal combustion engine, resulting in reduced emissions while maintaining the range and power of a conventional vehicle.

Electric vehicles, on the other hand, show a significant reduction in emissions compared to all other types of vehicles. The total emissions of EVs were only 451.20 KtCO2e, significantly lower than both BS6 and hybrid vehicles. This is due to the fact that EVs are powered solely by electricity, which is a cleaner source of energy compared to traditional gasoline or diesel.

Hydrogen fuel vehicles are the cleanest vehicles in terms of emissions, with only 180.48 KtCO2e emissions in total. These vehicles use hydrogen fuel cells to power their electric motors, producing only water vapor as a byproduct. While hydrogen fuel vehicles are not yet widely available, they hold great promise for the future as a potential clean alternative to traditional vehicles.

The data highlights the importance of transitioning to cleaner technologies in the transportation sector. It is crucial to encourage the adoption of EVs and hydrogen fuel vehicles to reduce the impact of greenhouse gas emissions on the environment. In addition, the Indian Army should continue to support the development and adoption of cleaner technologies by implementing policies that incentivize their use and promote their development.

The scenario analysis of emissions in the logistics sector reveals that the shift towards cleaner technologies, such as hybrid electric and diesel vehicles, EVs, and hydrogen fuel vehicles, can make a significant difference in reducing greenhouse gas emissions. While the transition may take time, the data shows that cleaner technologies offer a promising solution to mitigating climate change and promoting a more sustainable future for all. Next chapter deals with the finding out best technologies for reducing emissions by using cost benefit analysis and multi criteria analysis for the Indian Army.

CHAPTER 6

6. EVALUATING THE APPLICABILITY OF DIFFERENT GREEN TECHNOLOGIES USING COST BENEFIT ANALYSIS

The Indian Army is one of the largest standing armies in the world, with over 1.4 million active personnel. To support such a massive force, a wide range of vehicles is required, including trucks, jeeps, and other transport vehicles. Among these, the AL Stallion has become a popular choice in recent years, owing to its ruggedness, reliability, and versatility. The AL Stallion is a heavy-duty military vehicle manufactured by Ashok Leyland, an Indian automobile company. It has been in service with the Indian Army since 2010 and has proven to be a dependable workhorse in various operational conditions.

However, like all fossil fuel-based vehicles, the AL Stallion contributes to greenhouse gas emissions, which have adverse effects on the environment. As per the analysis of this study, the AL Stallion 7.5 alone emits in a range of 622.44 KtCO2e to 4,149.60 KtCO2e in 2022. Such a high level of emissions from a single vehicle type highlights the need for alternative fuels that are cleaner and more sustainable.

In this context, there has been a growing interest in developing alternative fuel-based vehicles that could be used in the military. Several countries, including the United States, China, and Russia, have already started exploring the possibility of using electric and hydrogen-based vehicles in their armies. In India, too, the government has launched several initiatives to promote the adoption of electric vehicles, with a focus on public transport and commercial vehicles.

Therefore, a cost-benefit analysis of the AL Stallion with its alternative fuel-based versions, including the BS6, electric, and hydrogen variants, is essential to evaluate the feasibility of the transition. This analysis would provide insights into the economic, social, and environmental impacts of each version of the vehicle, helping the Indian Army make an informed decision on which variant to adopt.

6.1 Possible alternatives for AL Stallion 7.5 tons:

There are three potential alternatives for the AL Stallion in the Indian Army, each with its own set of advantages and disadvantages. The first alternative is a diesel-powered AL Stallion with BS6 technology (Ashok Leyland, 2015). While less expensive upfront, the BS6 version emits fewer pollutants compared to BS3, making it a cleaner and more environmentally friendly option. The second alternative is an electric vehicle, the (GP Motors Technology, 2022). This vehicle has a higher upfront cost but lower energy prices, making it potentially more cost-effective in the long run. Additionally, the EV K100 has a much lower carbon footprint than its diesel counterparts, making it a more sustainable option. The third and final alternative is a hydrogen-powered vehicle, the Kia Hydrogen (Kia, 2022). The Kia Hydrogen has a very high upfront cost as well the cost of hydrogen is higher than diesel but emits only water vapor as a byproduct. This makes it the most environmentally friendly option of the BS3. The alternatives for AL Stallion 7.5 are summarized in the following table:

Fuel Type	Model	Upfront Cost (Rs)	Energy price (Rs) in 2022	Mileage (Km/L or KWh or Kg)
Diesel (BS3)	AL Stallion	2500000[27]	90 per L[28]	3.5
Diesel (BS6)	AL Stallion	3000000[29]	95 per L[30]	4.38
Electric	EV K100	5000000[31]	7 per unit[32]	0.6
Hydrogen	Kia Hydrogen[33]	6000000[34]	300 per Kg[35]	6

Table 12 Greener alternatives to AL Stallion 7.5

6.2 Standard Assumptions

The standard assumptions for cost and benefit analysis of greener alternatives to Al Stallion 7.5 tons have been provided in a table. The assumptions include an annual distance traveled of 15,000 kilometers, an annual rate of increase in fuel prices of 5%, maintenance cost as a percentage of upfront cost of 5%, and a discount rate of 5%. These assumptions will be used to calculate the cost and benefits of adopting greener alternatives to the Al Stallion 7.5 tons. However, it is important to note that these assumptions may not be applicable to all scenarios and may require adjustments based on specific circumstances. Proper analysis and consideration of all relevant factors are essential to making informed decisions regarding greener alternatives.

Annual distance traveled (Km)	15000
Annual rate of increase in price of fuel	5%
Maintenance Cost as percentage of upfront cost	5%
Discount rate	5%

Table 13 Standard assumptions

[27] (Truck Junction, 2022)
[28] (Ministry of Petroleum and Natural Gas, 2022)
[29] (Truck Junction, 2022)
[30] (Ministry of Petroleum and Natural Gas, 2022)
[31] (GP Motors Technology, 2022)
[32] (Statista, 2023)
[33] (Kia, 2022)
[34] (Elnozahy et al., 2015, p7)
[35] (Singh, 2022)

6.3 Cost Calculations

When calculating the cost of owning and operating a greener alternative to Ashok Leyland Stallion BS3 truck over a given period, there are three main factors to consider: upfront cost, maintenance cost, and fuel cost.

Cost = Upfront cost + Maintenance cost + Fuel cost

The upfront cost is the initial cost of purchasing the truck, which can vary depending on the make and model of the truck, as well as any customization or additional features. Here the study is considering the models having a purchasing cost mentioned in table 14.

The maintenance cost is the cost of keeping the truck in good working condition, which can include regular servicing, repairs, and replacement of parts. To estimate the maintenance cost, a standard assumption is to take a percentage of the upfront cost, typically between 3% and 10% (Norbu, 2019).

The fuel cost is the cost of fuel required to operate the truck over the given period, which can depend on factors such as the distance covered, the fuel efficiency of the truck, and the price of fuel. Based on the fuel efficiency of the truck, to calculate the amount of fuel required to cover the distance and multiplied it by the price of fuel, assuming it increases annually at a 5% (Norbu, 2019).

6.4 Benefits Calculations

In this study, the benefits are nothing but avoided emissions. To give monetary value to avoided emissions this study uses the social cost of carbon dioxide emissions. The social cost of carbon dioxide (SCC) is an economic estimate of the damage caused by each additional ton of carbon dioxide emitted into the atmosphere. It includes the costs associated with climate change impacts, such as health effects, property damage, and changes in ecosystem services. The SCC is used to inform policy decisions about climate change mitigation and carbon pricing. For the year 2022 it is $158 per ton of CO_2 emission (Kikstra et al., 2021).

The transportation cost of 1 ton of goods in India per km by road can vary depending on several factors, such as the distance traveled, the type of goods being transported, the mode of transportation, and the prevailing market conditions. However, as a rough estimate, the average transportation cost for 1 ton of goods by road in India can range from Rs. 3 to Rs. 5 per km, depending on the factors mentioned above. In this study it is considered to be Rs. 3.6 per ton per kilometer (Sun, 2022).

$$\text{Annual Cost of Transportation in Rs. (Year 2022)} = 3.6*15000*7.5 = 405000$$

Here for analysis, it is assumed that annual cost of transportation would increase at a minimum rate of 2% considering the volatility in factors of the transportation sector.

Benefits= Avoided CO2 emissions in tons * Social Cost of Carbon (Rs.) + Annual Cost of Transportation (Rs.)

6.5 Output of Cost Benefit Analysis for AL Stallion (BS6)

Year	Calendar Year	Upfront Cost (Rs.)	Maintenance Cost (Rs.)	Fuel Cost (Rs.)	Total Cost (Rs.)	Reduction in GHG (tCO_2e)	Social Cost of Carbon ($)	Value of one rupee to one usd	Social Cost of Carbon (Rs)	Annual Cost of Transport (Rs)	Total Discounted Benefits	Total Discounted Cost (Rs.)	Net Discounted Benefits (Rs.)	Cumulative Cost (Rs.)	Cumulative Benefits (Rs.)
1	2022	3000000	150000.00	325714.29	3475714.29	2.223	158.00	82.00	28801.19	405000.00	0.00	3475714.29	-3475714.29	3475714.29	0.00
2	2023	0	150000.00	342000.00	492000.00	2.223	165.90	83.64	30846.07	413100.00	433801.19	468571.43	-34770.24	3944285.71	433801.19
3	2024	0	150000.00	359100.00	509100.00	2.223	174.20	85.31	33036.14	421362.00	443946.07	461768.71	-17822.64	4406054.42	877747.26
4	2025	0	150000.00	377055.00	527055.00	2.223	182.90	87.02	35381.71	429789.24	454398.14	455289.93	-891.78	4861344.35	1332145.40
5	2026	0	150000.00	395907.75	545907.75	2.223	192.05	88.76	37893.81	438385.02	465170.95	449119.66	16051.29	5310464.00	1797316.35
6	2027	0	150000.00	415703.14	565703.14	2.223	201.65	90.53	40584.27	447152.73	476278.84	443243.21	33035.63	5753707.21	2273595.19
7	2028	0	150000.00	436488.29	586488.29	2.223	211.74	92.35	43465.75	456095.78	487737.00	437646.60	50090.40	6191353.81	2761332.19
8	2029	0	150000.00	458312.71	608312.71	2.223	222.32	94.19	46551.82	465217.70	499561.53	432316.49	67245.05	6623670.30	3260893.72
9	2030	0	150000.00	481228.34	631228.34	2.223	233.44	96.08	49857.00	474522.05	511769.52	427240.19	84529.33	7050910.49	3772663.24
10	2031	0	150000.00	505289.76	655289.76	2.223	245.11	98.00	53396.85	484012.49	524379.05	422405.62	101973.43	7473316.11	4297042.29

11	2032	0	150000.00	530554.25	680554.25	2.223	257.37	99.96	57188.03	493692.74	537409.34	417801.27	119608.07	7891117.38	4834451.63
12	2033	0	150000.00	557081.96	707081.96	2.223	270.23	101.96	61248.38	503566.59	550880.77	413416.18	137464.59	8304533.56	5385332.40
13	2034	0	150000.00	584936.06	734936.06	2.223	283.75	104.00	65597.01	513637.93	564814.97	409239.90	155575.07	8713773.46	5950147.37
14	2035	0	150000.00	614182.86	764182.86	2.223	297.93	106.08	70254.40	523910.69	579234.94	405262.49	173972.45	9119035.95	6529382.31
15	2036	0	150000.00	644892.01	794892.01	2.223	312.83	108.20	75242.46	534388.90	594165.08	401474.48	192690.61	9520510.43	7123547.39
16	2037	0	150000.00	677136.61	827136.61	2.223	328.47	110.36	80584.68	545076.68	609631.36	397866.85	211764.51	9918377.28	7733178.75
17	2038	0	150000.00	710993.44	860993.44	2.223	344.89	112.57	86306.19	555978.21	625661.35	394431.01	231230.34	10312808.29	8358840.11
18	2039	0	150000.00	746543.11	896543.11	2.223	362.14	114.82	92433.93	567097.77	642284.40	391158.79	251125.61	10703967.08	9001124.51
19	2040	0	150000.00	783870.26	933870.26	2.223	380.25	117.12	98996.74	578439.73	659531.70	388042.38	271489.32	11092009.46	9660656.21
20	2041	0	150000.00	823063.78	973063.78	2.223	399.26	119.46	106025.50	590008.52	677436.47	385074.38	292362.09	11477083.84	10338092.67
21	2042	0	150000.00	864216.97	1014216.97	2.223	419.22	121.85	113553.32	601808.70	696034.03	382247.71	313786.32	11859331.55	11034126.70
22	2043	0	150000.00	907427.82	1057427.82	2.223	440.18	124.28	121615.60	613844.87	715362.01	379555.64	335806.37	12238887.19	11749488.71
23	2044	0	150000.00	952799.21	1102799.21	2.223	462.19	126.77	130250.31	626121.77	735460.47	376991.77	358468.70	12615878.96	12484949.18
24	2045	0	150000.00	1000439.17	1150439.17	2.223	485.30	129.31	139498.08	638644.20	756372.08	374549.98	381822.09	12990428.94	13241321.26
25	2046	0	150000.00	1050461.12	1200461.12	2.223	509.57	131.89	149402.44	651417.09	778142.28	372224.47	405917.81	13362653.41	14019463.54
26	2047	0	150000.00	1102984.18	1252984.18	2.223	535.04	134.53	160010.02	664445.43	800819.53	370009.70	430809.83	13732663.11	14820283.07

27	2048	0	150000.00	1158133.39	1308133.39	2.223	561.80	137.22	171370.73	677734.34	824455.45	367900.40	456555.05	14100563.51	15644738.52
28	2049	0	150000.00	1216040.06	1366040.06	2.223	589.89	139.96	183538.05	691289.02	849105.07	365891.53	483213.53	14466455.04	16493843.58
29	2050	0	150000.00	1276842.06	1426842.06	2.223	619.38	142.76	196569.25	705114.80	874827.07	363978.33	510848.74	14830433.37	17368670.66
30	2051	0	150000.00	1340684.17	1490684.17	2.223	650.35	145.62	210525.67	719217.10	901684.06	362156.23	539527.82	15192589.61	18270354.71
										Total	18270354.71	15192589.61	3077765.10	NPV	
													1.202583311	BC Ratio	
													3%	IRR	

Table 14 Output of Cost Benefit Analysis for AL Stallion (BS6)

6.6 Output of Cost Benefit Analysis for Electric Vehicle

Year	Calendar Year	Upfront Cost (Rs.)	Maintenance Cost (Rs.)	Fuel Cost (Rs.)	Total Cost (Rs.)	Reduction in GHG (tCO2e)	Social Cost of Carbon ($)	Value of one rupee to one usd	Social Cost of Carbon (Rs)	Annual Cost of Transport (Rs)	Total Discounted Benefits	Total Discounted Cost (Rs.)	Net Discounted Benefits (Rs.)	Cumulative Cost (Rs.)	Cumulative Benefits (Rs.)
1	2022	5000000	250000.00	175000.00	5425000.00	4.446	158.00	82.00	57602.38	405000.00	0.00	5425000.00	-5425000.00	5425000.00	0.00
2	2023	0	250000.00	183750.00	433750.00	4.446	165.90	83.64	61692.14	413100.00	462602.38	413095.24	49507.14	5838095.24	462602.38
3	2024	0	250000.00	192937.50	442937.50	4.446	174.20	85.31	66072.29	421362.00	474792.14	401757.37	73034.78	6239852.61	937394.52
4	2025	0	250000.00	202584.38	452584.38	4.446	182.90	87.02	70763.42	429789.24	487434.29	390959.40	96474.89	6630812.01	1424828.81
5	2026	0	250000.00	212713.59	462713.59	4.446	192.05	88.76	75787.62	438385.02	500552.66	380675.62	119877.04	7011487.63	1925381.47
6	2027	0	250000.00	223349.27	473349.27	4.446	201.65	90.53	81168.54	447152.73	514172.65	370881.54	143291.11	7382369.17	2439554.11
7	2028	0	250000.00	234516.74	484516.74	4.446	211.74	92.35	86931.51	456095.78	528321.27	361553.85	166767.42	7743923.02	2967875.38
8	2029	0	250000.00	246242.57	496242.57	4.446	222.32	94.19	93103.65	465217.70	543027.29	352670.33	190356.96	8096593.35	3510902.67
9	2030	0	250000.00	258554.70	508554.70	4.446	233.44	96.08	99714.01	474522.05	558321.34	344209.84	214111.50	8440803.19	4069224.01
10	2031	0	250000.00	271482.44	521482.44	4.446	245.11	98.00	106793.70	484012.49	574236.06	336152.23	238083.83	8776955.42	4643460.07
11	2032	0	250000.00	285056.56	535056.56	4.446	257.37	99.96	114376.05	493692.74	590806.19	328478.31	262327.88	9105433.73	5234266.26

12	2033	0	250000.00	299309.39	549309.39	4.446	270.23	101.96	122496.75	503566.59	608068.79	321169.82	286898.97	9426603.55	5842335.05
13	2034	0	250000.00	314274.86	564274.86	4.446	283.75	104.00	131194.02	513637.93	626063.35	314209.35	311853.99	9740812.91	6468398.40
14	2035	0	250000.00	329988.60	579988.60	4.446	297.93	106.08	140508.80	523910.69	644831.95	307580.34	337251.61	10048393.25	7113230.35
15	2036	0	250000.00	346488.03	596488.03	4.446	312.83	108.20	150484.92	534388.90	664419.48	301266.99	363152.50	10349660.24	7777649.83
16	2037	0	250000.00	363812.43	613812.43	4.446	328.47	110.36	161169.35	545076.68	684873.82	295254.27	389619.55	10644914.51	8462523.66
17	2038	0	250000.00	382003.05	632003.05	4.446	344.89	112.57	172612.38	555978.21	706246.03	289527.88	416718.15	10934442.39	9168769.69
18	2039	0	250000.00	401103.21	651103.21	4.446	362.14	114.82	184867.85	567097.77	728590.59	284074.17	444516.41	11218516.56	9897360.27
19	2040	0	250000.00	421158.37	671158.37	4.446	380.25	117.12	197993.47	578439.73	751965.63	278880.16	473085.47	11497396.73	10649325.90
20	2041	0	250000.00	442216.28	692216.28	4.446	399.26	119.46	212051.01	590008.52	776433.20	273933.49	502499.71	11771330.21	11425759.10
21	2042	0	250000.00	464327.10	714327.10	4.446	419.22	121.85	227106.63	601808.70	802059.53	269222.37	532837.16	12040552.59	12227818.64
22	2043	0	250000.00	487543.45	737543.45	4.446	440.18	124.28	243231.20	613844.87	828915.33	264735.59	564179.73	12305288.18	13056733.96
23	2044	0	250000.00	511920.63	761920.63	4.446	462.19	126.77	260500.62	626121.77	857076.07	260462.47	596613.60	12565750.64	13913810.04
24	2045	0	250000.00	537516.66	787516.66	4.446	485.30	129.31	278996.16	638644.20	886622.38	256392.83	630229.56	12822143.47	14800432.42
25	2046	0	250000.00	564392.49	814392.49	4.446	509.57	131.89	298804.89	651417.09	917640.36	252516.98	665123.39	13074660.45	15718072.78
26	2047	0	250000.00	592612.11	842612.11	4.446	535.04	134.53	320020.04	664445.43	950221.97	248825.69	701396.28	13323486.14	16668294.76
27	2048	0	250000.00	622242.72	872242.72	4.446	561.80	137.22	342741.46	677734.34	984465.46	245310.18	739155.28	13568796.33	17652760.22

28	2049	0	250000.00	653354.86	903354.86	4.446	589.89	139.96	367076.10	691289.02	1020475.79	241962.08	778513.71	13810758.40	18673236.01
29	2050	0	250000.00	686022.60	936022.60	4.446	619.38	142.76	393138.50	705114.80	1058365.12	238773.41	819591.71	14049531.81	19731601.14
30	2051	0	250000.00	720323.73	970323.73	4.446	650.35	145.62	421051.34	719217.10	1098253.31	235736.58	862516.73	14285268.39	20829854.44
										Total	20829854.44	14285268.39	6544586.05	NPV	
													1.458135323	BC Ratio	
													4%	IRR	

Table 15 Output of Cost Benefit Analysis for Electric Vehicle

6.7 Output of Cost Benefit Analysis for Hydrogen Vehicle

Year	Calendar Year	Upfront Cost (Rs.)	Maintenance Cost (Rs.)	Fuel Cost (Rs.)	Total Cost (Rs.)	Reduction in GHG (tCO2e)	Social Cost of Carbon ($)	Value of one rupee to one usd	Social Cost of Carbon (Rs)	Annual Cost of Transport (Rs)	Total Discounted Benefits	Total Discounted Cost (Rs.)	Net Discounted Benefits (Rs.)	Cumulative Cost (Rs.)	Cumulative Benefits (Rs.)
1	2022	6000000	300000.00	750000.00	7050000.00	7.1136	158.00	82.00	92163.80	405000.00	0.00	7050000.00	-7050000.00	7050000.00	0.00
2	2023	0	300000.00	720000.00	1020000.00	7.1136	165.90	83.64	98707.43	413100.00	497163.80	971428.57	-474264.77	8021428.57	497163.80
3	2024	0	300000.00	691200.00	991200.00	7.1136	174.20	85.31	105715.66	421362.00	511807.43	899047.62	-387240.19	8920476.19	1008971.23
4	2025	0	300000.00	663552.00	963552.00	7.1136	182.90	87.02	113221.47	429789.24	527077.66	832352.45	-305274.79	9752828.64	1536048.89
5	2026	0	300000.00	637009.92	937009.92	7.1136	192.05	88.76	121260.20	438385.02	543010.71	770880.38	-227869.67	10523709.02	2079059.60
6	2027	0	300000.00	611529.52	911529.52	7.1136	201.65	90.53	129869.67	447152.73	559645.22	714207.23	-154562.01	11237916.25	2638704.82
7	2028	0	300000.00	587068.34	887068.34	7.1136	211.74	92.35	139090.42	456095.78	577022.39	661944.05	-84921.66	11899860.30	3215727.22
8	2029	0	300000.00	563585.61	863585.61	7.1136	222.32	94.19	148965.84	465217.70	595186.20	613734.17	-18547.97	12513594.47	3810913.41

9	2030	0	300000.00	541042.18	841042.18	7.1136	233.44	96.08	159542.41	474522.05	614183.53	569250.46	44933.08	13082844.93	4425096.94
10	2031	0	300000.00	519400.50	819400.50	7.1136	245.11	98.00	170869.92	484012.49	634064.46	528192.87	105871.59	13611037.79	5059161.40
11	2032	0	300000.00	498624.48	798624.48	7.1136	257.37	99.96	183001.69	493692.74	654882.41	490286.15	164596.26	14101323.95	5714043.81
12	2033	0	300000.00	478679.50	778679.50	7.1136	270.23	101.96	195994.80	503566.59	676694.43	455277.78	221416.65	14556601.72	6390738.24
13	2034	0	300000.00	459532.32	759532.32	7.1136	283.75	104.00	209910.44	513637.93	699561.40	422936.01	276625.38	14979537.74	7090299.64
14	2035	0	300000.00	441151.03	741151.03	7.1136	297.93	106.08	224814.08	523910.69	723548.36	393048.21	330500.15	15372585.95	7813848.00
15	2036	0	300000.00	423504.98	723504.98	7.1136	312.83	108.20	240775.88	534388.90	748724.76	365419.18	383305.58	15738005.13	8562572.76
16	2037	0	300000.00	406564.78	706564.78	7.1136	328.47	110.36	257870.96	545076.68	775164.78	339869.74	435295.03	16077874.87	9337737.54
17	2038	0	300000.00	390302.19	690302.19	7.1136	344.89	112.57	276179.80	555978.21	802947.64	316235.39	486712.25	16394110.26	10140685.18
18	2039	0	300000.00	374690.11	674690.11	7.1136	362.14	114.82	295788.57	567097.77	832158.01	294365.06	537792.95	16688475.32	10972843.19
19	2040	0	300000.00	359702.50	659702.50	7.1136	380.25	117.12	316789.56	578439.73	862886.34	274120.02	588766.33	16962595.33	11835729.53
20	2041	0	300000.00	345314.40	645314.40	7.1136	399.26	119.46	339281.61	590008.52	895229.29	255372.82	639856.46	17217968.16	12730958.82
21	2042	0	300000.00	331501.83	631501.83	7.1136	419.22	121.85	363370.61	601808.70	929290.14	238006.40	691283.74	17455974.55	13660248.96
22	2043	0	300000.00	318241.75	618241.75	7.1136	440.18	124.28	389169.92	613844.87	965179.30	221913.16	743266.15	17677887.71	14625428.26
23	2044	0	300000.00	305512.08	605512.08	7.1136	462.19	126.77	416800.99	626121.77	1003014.79	206994.23	796020.56	17884881.94	15628443.06
24	2045	0	300000.00	293291.60	593291.60	7.1136	485.30	129.31	446393.86	638644.20	1042922.75	193158.72	849764.03	18078040.66	16671365.81

25	2046	0	300000.00	281559.94	581559.94	7.1136	509.57	131.89	478087.82	651417.09	1085038.06	180323.07	904714.99	18258363.73	17756403.87
26	2047	0	300000.00	270297.54	570297.54	7.1136	535.04	134.53	512032.06	664445.43	1129504.91	168410.44	961094.46	18426774.17	18885908.78
27	2048	0	300000.00	259485.64	559485.64	7.1136	561.80	137.22	548386.33	677734.34	1176477.48	157350.15	1019127.33	18584124.33	20062386.26
28	2049	0	300000.00	249106.21	549106.21	7.1136	589.89	139.96	587321.76	691289.02	1226120.67	147077.18	1079043.49	18731201.50	21288506.93
29	2050	0	300000.00	239141.96	539141.96	7.1136	619.38	142.76	629021.61	705114.80	1278610.78	137531.68	1141079.10	18868733.19	22567117.71
30	2051	0	300000.00	229576.28	529576.28	7.1136	650.35	145.62	673682.14	719217.10	1334136.41	128658.61	1205477.80	18997391.80	23901254.12
										Total	23901254.12	18997391.80	4903862.33	NPV	
													1.258133452	BC Ratio	
													2%	IRR	

Table 16 Output of Cost Benefit Analysis for Hydrogen Vehicle

6.8 Comparison of break-even point - BS6, Electric and Hydrogen Vehicles

6.8.1 BS6 Vehicles

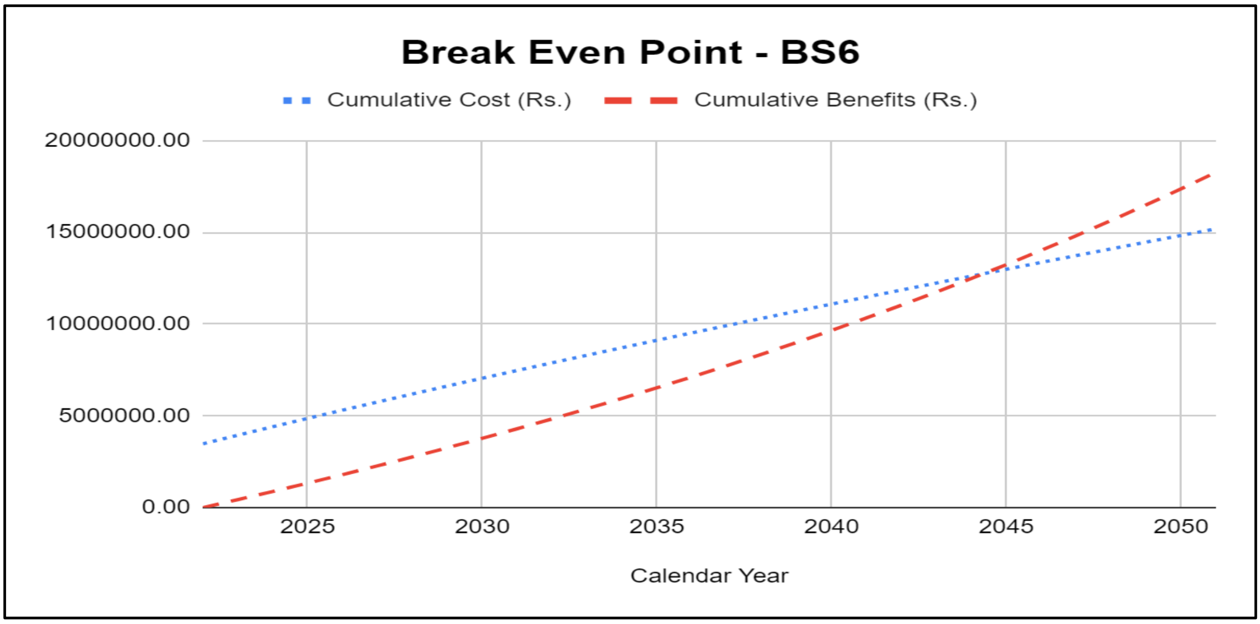

Figure 9 Break-even point B6 vehicle

6.8.2 Electric Vehicles

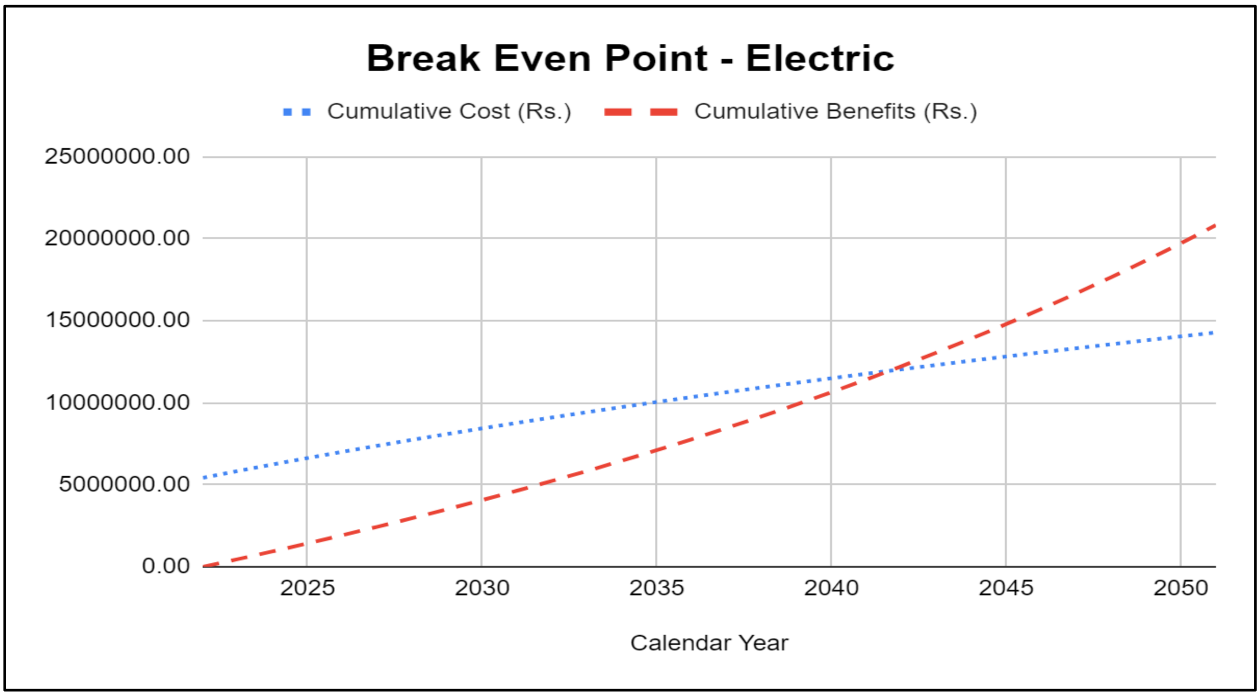

Figure 10 Break-even point Electric vehicle

6.8.3 Hydrogen fuel vehicles

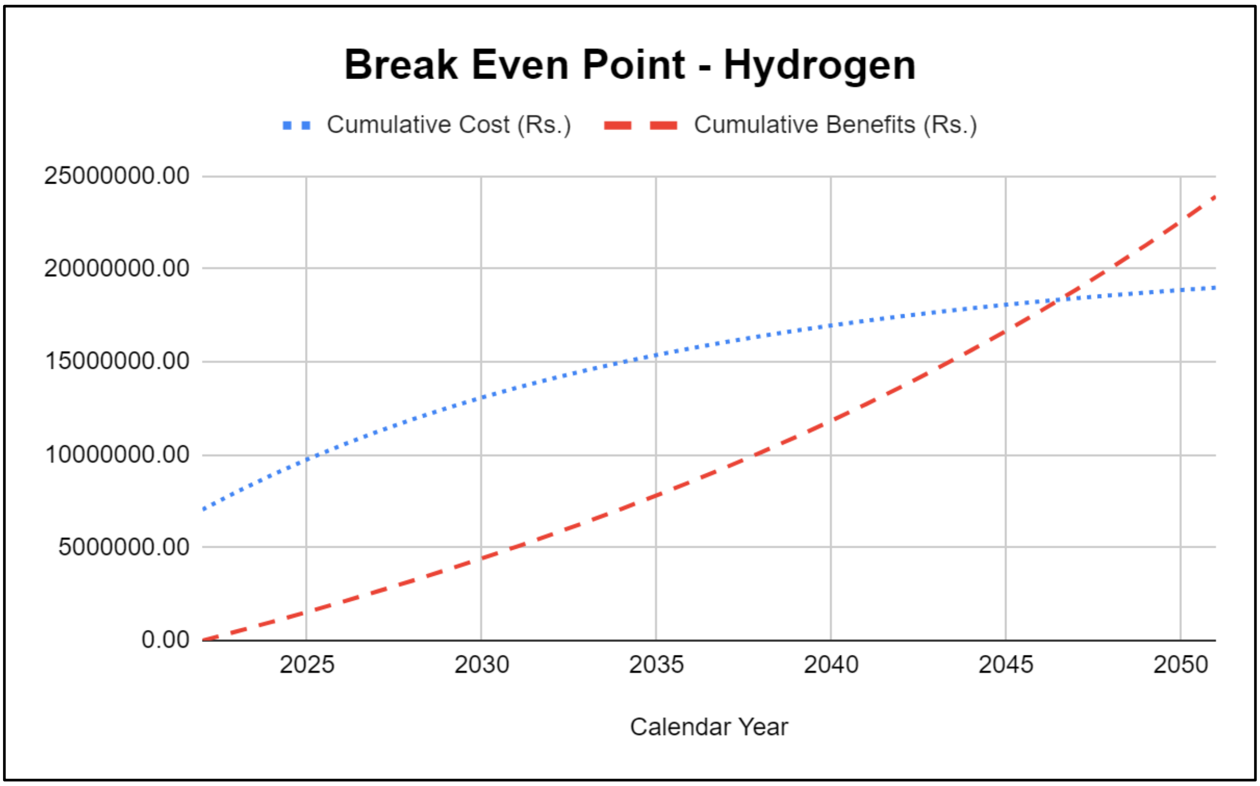

Figure 11 Break-even point Hydrogen vehicle

6.9 Cost Benefit Analysis - Conclusion

The purpose of this cost benefit analysis is to compare the costs and benefits of replacing AL Stallion 7.5 vehicles with three different types of vehicles: Bharat Stage VI (Ashok Stallion 7.5), electric (EV K100), and hydrogen fuel (Kia Hydrogen). The analysis considers the total benefits and costs over a period of 30 years for each option, as well as the net present value (NPV), benefit-cost ratio (BCR), internal rate of returns (IRR), and break-even point year.

The results show that the electric vehicle option has the highest BCR of 1.458135323, meaning that it generates more benefits than costs compared to the other options. It also has the highest NPV of Rs 6544586, which means that it has the highest value in today's terms after accounting for inflation and discounting. Moreover, it has the highest IRR of 4.33%, which indicates that it has the highest return on investment among the alternatives. Finally, it has the earliest break-even point year of 2042, which means that it recovers its initial costs faster than the other options.

The second-best option is the hydrogen fuel vehicle option, which has a BCR of 1.258133452, an NPV of Rs 4903862, an IRR of 2.13%, and a break-even point year of 2046. The third best option is the Bharat Stage VI vehicle option, which has a BCR of 1.202583311, an NPV of Rs 3077765, an IRR of 3.12%, and a break-even point year of 2044.

Type of Vehicles	Model	Net Present Value (NPV) Rs.	Benefit-Cost Ratio	Internal Rate of Returns	Break-even point year
Bharat Stage VI	Ashok Stallion 7.5	3077765.103	1.202583311	3.12%	2044
Electric	EV K100	6544586.049	1.458135323	4.33%	2042
Hydrogen Fuel	Kia Hydrogen	4903862.328	1.258133452	2.13%	2046

Table 17 Summary of Cost-Benefit Analysis

Based on these findings, it can be concluded that replacing the AL Stallion 7.5 vehicle with an Electric engine is the most beneficial option among the three alternatives considering the reduction of greenhouse gas emissions. Overall, the electric vehicle appears to be a highly promising alternative for the Indian Army, offering significant financial benefits and a lower environmental impact. In the next section, this study analyzes the viability of different technology using multi criteria analysis.

CHAPTER 7

7. EVALUATING THE APPLICABILITY OF DIFFERENT GREEN TECHNOLOGIES USING MULTI CRITERIA ANALYSIS

7.1 Defining Criteria

Multi-criteria analysis is a decision-making technique that considers multiple criteria simultaneously in order to make an informed decision. It is used to evaluate different alternatives, taking into account different aspects that are relevant to the decision. Military vehicles are an example of a product where multi-criteria analysis can be applied. This study will discuss the application of multi-criteria analysis to military vehicles, considering different criteria such as Fuel Type, Upfront Cost (Rs), Fuel Cost (Rs.) per Year, Durability (Years), Range (Km), Operational Ease, CO2e (gm) Emissions per year.

7.1.1 Fuel Type

Fuel Type is an important criterion to consider when selecting military vehicles. Different types of fuels are available, such as diesel, electricity and hydrogen. Each fuel type has different advantages and disadvantages, and the choice of fuel type will depend on the specific requirements of the military. For example, hydrogen engines have higher fuel efficiency than diesel engines, which means that they consume less fuel for the same distance traveled. However, they also emit less pollutants and are more environmentally friendly than diesel engines. Hydrogen engines combine the advantages of both electric and diesel engines, but they are also more expensive.

7.1.2 Cost

Upfront Cost (Rs) is another criterion that needs to be considered when selecting military vehicles. The upfront cost of a vehicle includes the purchase price, installation costs, and any other associated costs. It is an important factor because it affects the total cost of ownership of the vehicle. Military vehicles are often expensive, so it is important to consider the upfront cost when selecting them. However, it is important to note that the upfront cost is not the only cost associated with owning a vehicle.

7.1.3 Fuel Cost

Fuel (Rs.) per Year is a criterion that is closely related to Fuel Type. It refers to the cost of fuel per year for the vehicle. This is an important criterion because it affects the operational cost of the vehicle. Vehicles that have high fuel efficiency will consume less fuel and therefore have lower fuel costs per year. Hydrogen engines generally have higher fuel costs per year than diesel engines because the technology is still evolving.

7.1.4 Durability

Durability (Years) is another important criterion to consider when selecting military vehicles. Military vehicles need to be able to withstand tough conditions and rough terrain. They also need to have a long lifespan because they are often used for many years. Durability is a measure of how long a vehicle can last before it needs to be replaced or repaired. Vehicles with high durability will last longer and therefore have a lower total cost of ownership.

7.1.5 Range

Range (Km) is another important criterion to consider when selecting military vehicles. The range of a vehicle is the distance it can travel on a single tank of fuel or charge. It is an important criterion because it affects the operational capability of the vehicle. Vehicles with high ranges can travel longer distances and therefore have more operational capability than vehicles with low ranges.

7.1.6 Operational Ease

Diesel vehicles have been the mainstay of military operations for many years due to their reliability and operational ease. Diesel vehicles are generally easier to maintain and operate than electric vehicles because of their simpler design, and they have the advantage of being able to draw fuel from existing military fuel supplies. Electric vehicles are becoming increasingly popular in the military due to their low noise and emissions, but they do require more complex maintenance and charging infrastructure. Hydrogen fuel cell vehicles offer the advantages of both diesel and electric vehicles, with the added bonus of zero emissions. However, they are still relatively new technology and require significant infrastructure investments to be deployed on a wide scale. All three types of vehicles have the potential to be operated in military environments, but diesel vehicles remain the most practical choice due to their proven track record and operational ease.

7.1.7 Emissions

CO2e (gm) Emissions per year BAU is a criterion that is related to Environmental Pollution. It refers to the amount of CO2 emissions that a vehicle produces per year under business-as-usual and key focus of this study. Following table provides an overview on parameters of the multi criteria analysis. The prime motive of this analysis is to find the most appropriate replacement for AL Stallion 7.5 running on Bharat Stage 3 engine.

Fuel Type	Model	Upfront Cost (Rs)	Fuel (Rs.) per Year	Durability (Years)	Range (Km)	Operational Ease		CO2e (gm) Emissions per year BAU
Diesel (BS3)[36]	AL Stallion	2500000	385714	10	800	High	3	8892000
Diesel (BS6)[37]	AL Stallion	3000000	325714	10	900	High	3	6669000
Electric[38]	EV K100	5000000	175000	15	300	Low	1	4446000
Hydrogen[39]	Kia Hydrogen	6000000	750000	15	1000	Medium	2	1778400

Table 18 Alternatives to AL Stallion 7.5

7.2 Normalization

Normalization is the process of converting different measures or scales of a set of criteria into a common scale to enable comparison and ranking of alternatives. In the context of multi-criteria analysis, normalization involves scaling the values of the criteria so that they all have equal weight or importance in the decision-making process. The normalization process ensures that no criteria dominate the decision-making process due to having larger values or scales.

To normalize the criteria, we use the equation:

$$\text{Normalized value} = (\text{Value} - \text{Min}) / (\text{Max} - \text{Min})$$

Where Min is the minimum value of the criteria, Max is the maximum value of the criteria, and Value is the value of the specific alternative for that criterion.

In the given example, the criteria are Fuel Type, Upfront Cost (Rs), Fuel (Rs.) per Year, Durability (Years), Range (Km), Operational Ease, Emissions per year BAU. The values for

[36] (Ashok Leyland, 2015)
[37] (Ashok Leyland, 2015)
[38] (GP Motors Technology, 2022)
[39] (Kia, 2022)

each alternative are also given. To normalize the values, we use the above equation for each criterion and alternative combination.

For example, to normalize the range (Km) per Year for Diesel (BS3) AL Stallion, we use the equation:

Normalized value = (800 - 0)/ (1000 - 0) = 0.8

Similarly, we calculate the normalized values for each alternative and criteria combination. The resulting values are on a scale of 0 to 1, where 1 represents the best value for the criteria and 0 represents the worst value. Following table provides normalized values for the different criteria.

Fuel Type	Model	Upfront Cost (Rs)	Fuel (Rs.) per Year	Durability (Years)	Range (Km)	Operational Ease	CO2e (gm) Emissions per year BAU
Diesel (BS3)	AL Stallion	1.0000	0.4537	0.6667	0.8000	1.0000	0.2000
Diesel (BS6)	AL Stallion	0.8333	0.5373	0.6667	0.9000	1.0000	0.2667
Electric	EV K100	0.5000	1.0000	1.0000	0.3000	0.3333	0.4000
Hydrogen	Kia Hydrogen	0.4167	0.2333	1.0000	1.0000	0.6667	1.0000

Table 19 Normalization Output

7.3 Weights assignment

The rationale behind assigning weights to the criteria is to reflect their relative importance in the decision-making process. The weights represent the degree of importance that decision-makers place on each criterion when evaluating the alternatives.

In the case of military vehicles, the weights assigned to the criteria are based on several factors. For instance, upfront cost and fuel cost are crucial considerations for the military, as it has a limited budget and has to ensure that the vehicles' maintenance and operating costs are within budget. Therefore, the weights assigned to the upfront cost and fuel cost criteria are relatively high (0.2 and 0.15, respectively).

Durability and range are other important factors in military vehicles' decision-making process. The military needs vehicles that can withstand harsh terrain and weather conditions and travel long distances without refueling. Therefore, these criteria are assigned a weight of 0.25 and 0.2, respectively.

Operational ease is also an essential factor in military vehicles' decision-making process as it can impact the vehicles' ability to get ready in all weather conditions. The weight assigned to the operational ease criterion is (0.1), reflecting its importance compared to other criteria. CO2 emissions are also becoming increasingly important considerations for military vehicles, reflecting the military's commitment to sustainable and environmentally friendly operations. Therefore, these criteria are assigned a weight of (0.1).

Overall, the weights assigned to the criteria reflect the military's priorities and requirements for their vehicles, taking into account budget constraints, performance, and sustainability considerations. Following table summarizes the assigned weights.

Upfront Cost (Rs)	Fuel (Rs.) per Year	Durability (Years)	Range (Km)	Operational Ease	CO2e (gm) Emissions per year BAU
0.2	0.15	0.25	0.2	0.1	0.1

Table 20 Weights

7.4 Results of Multi Criteria Analysis

The final scores represent the weighted and normalized values for each criterion for each vehicle model. To calculate the final scores, the normalized values are multiplied by their respective weights and added together for each vehicle model.

For example, for the AL Stallion Diesel (BS3) model, the weighted and normalized values for each criterion are:

Upfront Cost (Rs) = 0.2 x 1.0000 = 0.2000

Fuel (Rs.) per Year = 0.15 x 0.4537 = 0.06806

Durability (Years) = 0.25 x 0.6667 = 0.1667

Range (Km) = 0.2 x 0.8000 = 0.1600

Operational Ease =0.1 x 1 = 0.1

CO_2e (gm) Emissions per year BAU = 0.1 x 0.2000 = 0.0200

The total weighted score is the sum of the above values, which is 0.71472. This value represents the overall score for this vehicle model based on the relative importance of each criterion. Similarly, the final scores for the other vehicle models are calculated in the same way, and the highest score represents the best option for the military's requirements.

Fuel Type	Model	Upfront Cost (Rs)	Fuel (Rs.) per Year	Durability (Years)	Range (Km)	Operational Ease	CO2e (gm) Emissions per year BAU	Score
Diesel (BS3)	AL Stallion	0.20000	0.06806	0.16667	0.16000	0.10000	0.02000	0.71472
Diesel (BS6)	AL Stallion	0.16667	0.08059	0.16667	0.18000	0.10000	0.02667	0.72059
Electric	EV K100	0.10000	0.15000	0.25000	0.06000	0.03333	0.04000	0.63333
Hydrogen	Kia Hydrogen	0.08333	0.03500	0.25000	0.20000	0.06667	0.10000	0.73500

Table 21 Output of Multi criteria analysis

Based on the multi-criteria analysis conducted for military vehicles, it is evident that there are multiple options available in terms of fuel type, model, upfront cost, fuel cost per year, durability, range, operational ease, CO_2 emissions per year and overall score. The four options evaluated were diesel (BS3), diesel (BS6), electric, and hydrogen.

After considering all the factors, it can be concluded that the Kia Hydrogen model is the most favorable option for the military. It has the lowest upfront cost, lowest fuel cost per year, longest durability, highest range, good operational ease, and lowest CO_2 emissions per year. It also scores the highest overall with a score of 0.73500.

The second most favorable option is the diesel (BS6) model, with a score of 0.72059. While it has a higher upfront cost and fuel cost per year than the Kia Hydrogen model, it still has a respectable score due to its durability, range, and operational ease.

The Electric model and the diesel (BS3) model, on the other hand, have lower scores compared to the other two options, mainly due to their lower durability, range, and operational ease. The Electric model has a score of 0.63333, while the diesel (BS3) model has a score of 0.71472.

In conclusion, the multi-criteria analysis highlights the importance of considering various factors when making decisions about military vehicles. The analysis shows that hydrogen-powered vehicles are the most favorable option for military use, followed by diesel (BS6) vehicles. However, it is important to note that other factors, such as availability of fuel and infrastructure, must also be taken into account when making decisions about military vehicles.

Hydrogen fuel cell vehicles are a promising option for military use due to their high efficiency, low emissions, and long-range capabilities. Unlike traditional diesel and electric vehicles, hydrogen fuel cell vehicles run on a clean, renewable energy source that produces only water vapor as a byproduct. This makes them a more environmentally friendly and sustainable option for military operations.

In terms of efficiency, hydrogen fuel cell vehicles have a high energy density, meaning they can store a large amount of energy in a small volume. This allows for longer range capabilities compared to traditional electric vehicles, which are limited by the size and weight of their battery packs. With a hydrogen fuel cell vehicle, the military can travel further without the need for frequent recharging or refueling stops.

Hydrogen fuel cell vehicles are a more discreet option compared to diesel and electric vehicles. The quiet and vibration-free operation of hydrogen fuel cell vehicles makes them ideal for military operations that require a low profile. Additionally, the lack of emissions from hydrogen fuel cell vehicles makes them less detectable in the field, increasing their overall stealth capabilities.

In terms of environmental pollution, hydrogen fuel cell vehicles have a significant advantage over traditional diesel and electric vehicles. Unlike diesel and electric vehicles, which rely on fossil fuels or energy generated from fossil fuels, hydrogen fuel cell vehicles run on a clean, renewable energy source. This results in significantly lower emissions of harmful pollutants, making them a more environmentally friendly option for military operations.

In terms of CO_2 emissions, hydrogen fuel cell vehicles are also a more sustainable option. While electric vehicles produce no emissions during operation, the energy used to recharge their batteries often comes from sources that produce significant CO_2 emissions, such as coal and natural gas. On the other hand, hydrogen can be produced from a variety of renewable energy sources, including wind, solar, and hydro power, making it a cleaner and more sustainable source of energy.

In conclusion, hydrogen fuel cell vehicles are the best option for military use due to their high efficiency, low emissions, and long-range capabilities. Their clean, renewable energy source and stealthy operation make them ideal for military operations, while their low environmental impact and low CO_2 emissions make them a more sustainable and environmentally friendly option. While upfront costs may be higher compared to traditional diesel and electric vehicles, the long-term benefits of hydrogen fuel cell vehicles make them a more cost-effective option in the long run.

CHAPTER 8

8. CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The decarbonization of the transport sector is a crucial step towards achieving the goal of reducing greenhouse gas emissions and mitigating climate change. The military sector, being a significant contributor to global emissions, needs to take urgent steps to reduce its carbon footprint. In this context, this dissertation focuses on the Indian Army's transport sector and evaluates the applicability of different green technologies to reduce emissions.

The study begins by examining the current state of the Indian Army's transport sector and its carbon footprint. The econometric analysis reveals that the Indian military's greenhouse gas emissions for the year 2022 were around 36.568 MtCO2e, with stationary emissions contributing to 34.180 MtCO2e, and mobile emissions accounting for 2.387 MtCO2e. The Indian Army's transport emissions range from 902 to 6014 KtCO2e, which is significant.

The next step in the study is to evaluate the different green technologies that can be implemented in the Indian Army's transport sector. The study considers electric vehicles, hybrid vehicles and hydrogen vehicles as potential green technologies. The analysis reveals that each technology has its advantages and disadvantages, and the choice of technology depends on various factors such as cost, performance, and sustainability.

To determine the most suitable green technology for the Indian Army's transport sector, the study performs both cost-benefit and multi-criteria analysis. The cost-benefit analysis compares the costs and benefits of each technology and shows that electric vehicles are the best choice for the military in the short run. However, the multi-criteria analysis considers several factors such as performance, sustainability, security, and logistics, and reveals that hydrogen vehicles are the best choice considering the military's multiple requirements.

In conclusion, the dissertation highlights the urgent need for the Indian Army's transport sector to reduce its carbon footprint and mitigate climate change. The study evaluates the applicability of different green technologies and performs cost-benefit and multi-criteria analysis to identify the most suitable technology for the Indian Army's transport sector. The analysis reveals that hydrogen vehicles are the best choice considering the military's multiple requirements, although electric vehicles are the most feasible choice in the short run.

8.2 Future Scope

The future scope of this dissertation could involve further research on the feasibility and implementation of hydrogen vehicles in the Indian Army's transport sector. The study could also explore the potential challenges and solutions in integrating these green technologies into the military's existing infrastructure. Furthermore, the study could be extended to other military sectors globally, to identify suitable green technologies for the transport sector and reduce their carbon footprint.

Future scope of dissertation is to find out the potential challenges and solutions in implementing green technologies in the Indian Army's transport sector. The challenges include the lack of infrastructure, high initial costs, and concerns regarding the reliability and performance of green technologies. Also, to find out solutions such as developing the necessary infrastructure, offering incentives and subsidies to encourage the adoption of green technologies, and conducting pilot projects to assess the feasibility of different technologies

Overall, the decarbonization of the transport sector is a crucial step towards achieving sustainable development and mitigating climate change. The military sector needs to take urgent steps to reduce its carbon footprint and adopt green technologies to contribute to global efforts to mitigate climate change. The findings of this dissertation can serve as a useful guide for policymakers and military leaders to make informed decisions regarding the implementation of green technologies in the military's transport sector.

CHAPTER 9

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CHAPTER 10

10. APPENDIX

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