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Mitigating GHG Emissions from Military Supply Chain by Use of Aerial Cable Way

Prashant P. Bhave*, Chetan Dhawad and Vibha Jain

Civil and Environmental Engineering Department, Veermata Jijabai Technological Institute (VJTI), Mumbai - 400 019, India
**E-mail: ppbhave@ci.vjti.ac.in*

ABSTRACT

The transportation sector being one of the significant contributors to greenhouse gas (GHG) emission, there is growing concerns about environmental sustainability, and reducing GHG emissions which has prompted re-evaluation of transportation systems. The 1.5 million strong Indian defence forces have huge transport fleet and this study delves into the potential of Aerial Cableway (ACW) as a promising alternative mode of transport that can significantly reduce emissions of military supply chain in mountainous terrain. The study takes a case of Himalayan terrain to investigate how ACWs offer a low-impact, energy-efficient, and environmentally friendly solution compared to conventional ground-based transportation. It takes a case of Pharkian Pass in North Kashmir where defence forces has presence and this pass is often exposed to frequent landslides, snowfall and avalanches. Every year, on an average, approximately 12,000 trucks cross Pharkian pass in a year for purpose of logistics and sustenance. Without touching sensitive issues and by using a multi-criteria-based cost-benefit analysis, the study establishes that even if 75 % of road transport trips are shifted to ACWs, the reduction of GHG emissions is by 57.7 % in addition to significant benefits of the social cost of carbon, environmental costs, economic savings and ensuring strategic advantage like all-weather connectivity.

Keywords: Greenhouse Gas (GHG) emissions; Aerial cable way (ACW); Cost-benefit analysis (CBA); Emission reduction

NOMENCLATURE

GHG	: Greenhouse gas
ACW	: Aerial cableway
CBA	: Cost benefit analysis
COP	: Conference of parties
IEA	: International Energy Agency
WHO	: World Health Organisation
LCA	: Life cycle assessment
Km	: Kilometres
Min	: Minutes
Ltr	: Litre
CO_2	: Carbon dioxide

1. INTRODUCTION

The most pressing and imminent danger facing humanity in the coming decades is global warming. Despite three decades of global efforts to address climate change, there was an annual increase of 2.2 % in global Greenhouse Gas (GHG) emissions from 2000 to 2009, followed by a 1.3 % increase in the period from 2010 to 2019[1]. The Dubai conference, which concluded in December 2023, also referred as 'Conference of Parties' (COP-28) viewed world leaders assembling in desperation and agreeing on ambitious environment goals, thus attempting to restrict global temperature rise to 1.5° C.[2]

Continuously, India has maintained its status as the third-largest contributor of Greenhouse Gases (GHG) on a global scale, ranking only below China and the United States in terms of total emissions[3]. However, it is aspirational journey on various international platforms to emerge as 'Climate Power' by defining and chasing ambitious climate goals is praiseworthy. To achieve the decarbonisation, India is going through an unprecedented transition phase where traditional 'Economy', 'Industry', 'Fossil Fuel' 'Technology', 'Strategic Partnership', 'Bonds', and 'Transport' being replaced by 'Green Economy',' Green Industry', 'Green Fuel', 'Green Technology', 'Green Strategic Partnership', 'Green Bonds', and 'Green Transport' respectively.

According to the WHO[4], every year globally, seven million deaths annually are caused by air pollution. Serious environmental concerns stem from those Greenhouse Gases (GHG) produced by transportation systems based on the use of fossil fuels[5-6]. According to the International Energy Agency (IEA), around one-fifth of global CO_2emissions is due to transport sector," and among these, road travel contributes to 75 % of emissions(passenger vehicles and buses). Thus, the transport sector accounts for 14 % of CO_2, 30 % of NOx, 54 % of CO, and 47 % of non-methane hydrocarbon gases[7-8]. Among all these, the major GHG contributor is CO_2 which is considered to be main culprit for global warming[9]. Similarly, Indian transport contributes 14 % to its GHG inventory. Although various initiatives by the Indian government to channel fossil fuel-based transport to renewable energy are under progress,

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the same needs to be accelerated and thus Indian defence transport has a unique opportunity to switch its mammoth logistics chain to Arial Cable Way (ACW), particularly in mountainous terrain. Indian army is one of the largest public sector organisations and has more than one lakh heavy vehicles under command which are extensively deployed along the northern and north-eastern border states of India.

It is established that Air Cushion Vehicles (ACW) represent one of the most environmentally friendly transportation modes and are crucial in addressing the climate change crisis, especially in mountainous regions like the Himalayas. In such terrains, where heavy snowfall can isolate forward areas for nearly five months, disrupting road transportation, ACWs become essential for maintaining mobility.

Ensuring resilient transportation routes with minimal exposure to risk and a negligible reliance on fossil fuels, Air Cushion Vehicles present a promising solution. This paper marks the inaugural endeavour in India to pragmatically assess emission reductions resulting from transitioning transportation in mountainous regions from road to ACW, utilizing publicly available information without delving into sensitive security matters. The study additionally scrutinizes accomplishments through cost-benefit and multi-criteria analyses.

The paper presents a Life Cycle Assessment (LCA) of emissions from an ACW system, following ISO 14064 (2018) standards. The paper also compares the LCA emission of ACW with the conventional surface transport systems. Using the economic cost-benefit approach, the paper evaluates the multi-dimensional benefit of using ACW compared to a conventional transport system. The benefit-cost analysis involves- (i) reduction of fossil fuel consumption, (ii) environmental costs, (iii) operation and maintenance costs, and (iv) social cost.

1.1 Aerial Cable Way as Catalyst and an Integral Part of Sustainable Transport

Although, a universal definition for sustainable transport does not exist but the understanding provided by UN describes it as "Sustainable transport is the provision of services and infrastructure for the mobility of people and goods—advancing economic and social development to benefit today's and future generations-in a manner that is safe, affordable, accessible, efficient, and resilient, while minimising carbon and other emissions and environmental impacts"[10].

Aerial ropeway systems certainly considered as one of the promising sustainable mode of transport due to negligible carbon footprint (low emissions). The primary reason is low requirement of energy for the electric propulsion system used at the terminal and intermediary stations. The other major advantage is insignificant generation of noise along their route thus proved one of the quietest public transport systems. ACW is certainly technically proven and well established as one of the preferred modes of transport for decades particularly in prevailing over topographical challenges in rugged hilly regions.

In geographical contexts where road access is difficult or non-existent and when reducing travel time is a priority, ACW stands out as an attractive option to consider[11]. However, India is still in a nascent stage in ropeway development as compared to other countries. Compared to 4,000 active ropeways in France, 2,000 in the United States and 1,500 in Switzerland, India has barely 65 ropeway projects, and only 22 are successful[12].

In India, the transport sector emitted 258.1 Teragram (10^{12}) tons of CO_2e, representing 13.5 % of total emissions[13]. As evident in all cities of developing countries and in particularly in India, the consistent increase of traffic volume is beyond capacity for existing transport infrastructure. These increasing volumes have adverse effect on nature as well as humans. Thus, to meet global climate goals, revamping of existing transport is the need of an hour. ACW are a mode of transport which reduces the emission of particulate matter generated by road transport which uses fossil fuels. One of the studies in Colombia about cable car establishes that cable car transport have not only saved significant CO_2 emissions (more than 20 %) but also assisted in enhancing its ridership due to much faster commute(more than 10 % travel time savings)[14].

Conducted through a Life Cycle Assessment (LCA), a case study conducted in Kuelap, Peru, revealed that the integration of a cable car into public transportation offers significant environmental advantages over traditional road traffic in the geographical conditions of the Andes[15].

It is well known that cable cars are ecologically beneficial in mountainous terrain compared to conventional means of transport, as their directness and ease of overcoming differences in altitude are beneficial. Furthermore, cable cars are a well-tested technology from predominantly touristic mountain regions. The topographical terrain of Himalayan

Table 1. SWOT analysis of mountainous area in Kashmir

Strengths	Weakness
• Favorable topography for the construction of adequate ACW sites is available • Switching over the bulk of supply chain movement from road to ACW leads to a massive reduction in transport movement by road • Capable of functioning in all-weather situations • Major reduction in travel time • Safe movement even during nighttime in the mountains • Not susceptible to landslides despite being in the mountains.	• Additional precautions during heavy winds • Additional capacity of motors to negotiate gradient to be planned.
Opportunities	**Threats**
• Switching over from fossil fuel to renewables and setting the example for major government organization and corporations • Facilitating easier move of logistics • Inevitable transition to fight against climate change crisis.	• Infrastructure and movement would be susceptible to enemy fire during hostilities • During severe wind speed, operations may have to be halted.

areas in North and North-east states in India offers numerous strengths and opportunities compared to existing transport by road, and the same Strength-Weakness-Opportunity-Threat (SWOT) analysis is explained in Table 1.

2. METHODOLOGY

The paper's primary objective is to estimate emission reduction by comparing the current scenario (movement by road) to future methods (movement by ACW). To analyse the same, 'Pharkian Pass' in North Kashmir is chosen as a case study area where Indian forces are present.

2.1 Case Study Area and Proposal

Pharkian pass in the Kupwara district of North Kashmir offers one of the ideal topographical locations for the case study. Pharkian pass is at an altitude of 9800 feet, 42 km away from Kupwara city towards north on road axis Keren, a prominent village being developed as a tourist hub near the international border. From Kupwara town at an altitude of 5,500 feet, the road is almost on a level surface for 25 km till Melyal. The ascend starts from Melyal to Pharkian, and after crossing Pharkian, it descends to Patra. The crucial distances and travel time are summarised as follows.

Table 2. Distance and time chart

From	To	Distance (km)		Time (min)	
		Road	ACW	Road	ACW
Melyal	Pharkian	17	3	60	14
Pharkian	Patra	8	1.6	45	6
Kupwara	Melyal	25	-	50	-
Patra	Keren	20	-	50	-

2.1.1 Proposal

It is proposed to construct ACW for a distance of 4.6 km, instead of travelling by road from Melyal to Patra for a distance of 17+8=25 km (Turn around distance=50 km), as shown in Fig. 1.

2.1.2 Quantum of Logistics Under Consideration

The ascend towards Pharkian pass is challenging to negotiate, notably for a truck carrying more than one ton of load hence, the defence authoritiesrecommend carrying a truckload of up to one ton. According to the state authorities manning the Pharkian pass, the number of vehicles with logistics sustenance in a year is 12,000. These vehicles are primarily diesel-powered military trucks called 2.5 Ton trucks, with a fuel efficiency of 4.5 Km/ltr.

These trucks heavily emit nitrogen oxides (NOx), particulate matter (PM), and CO_2, all harmful to the environment and human health. According to a study, the 2.5 truck emit 307 gm of CO_2 equivalent per kilometre[16].

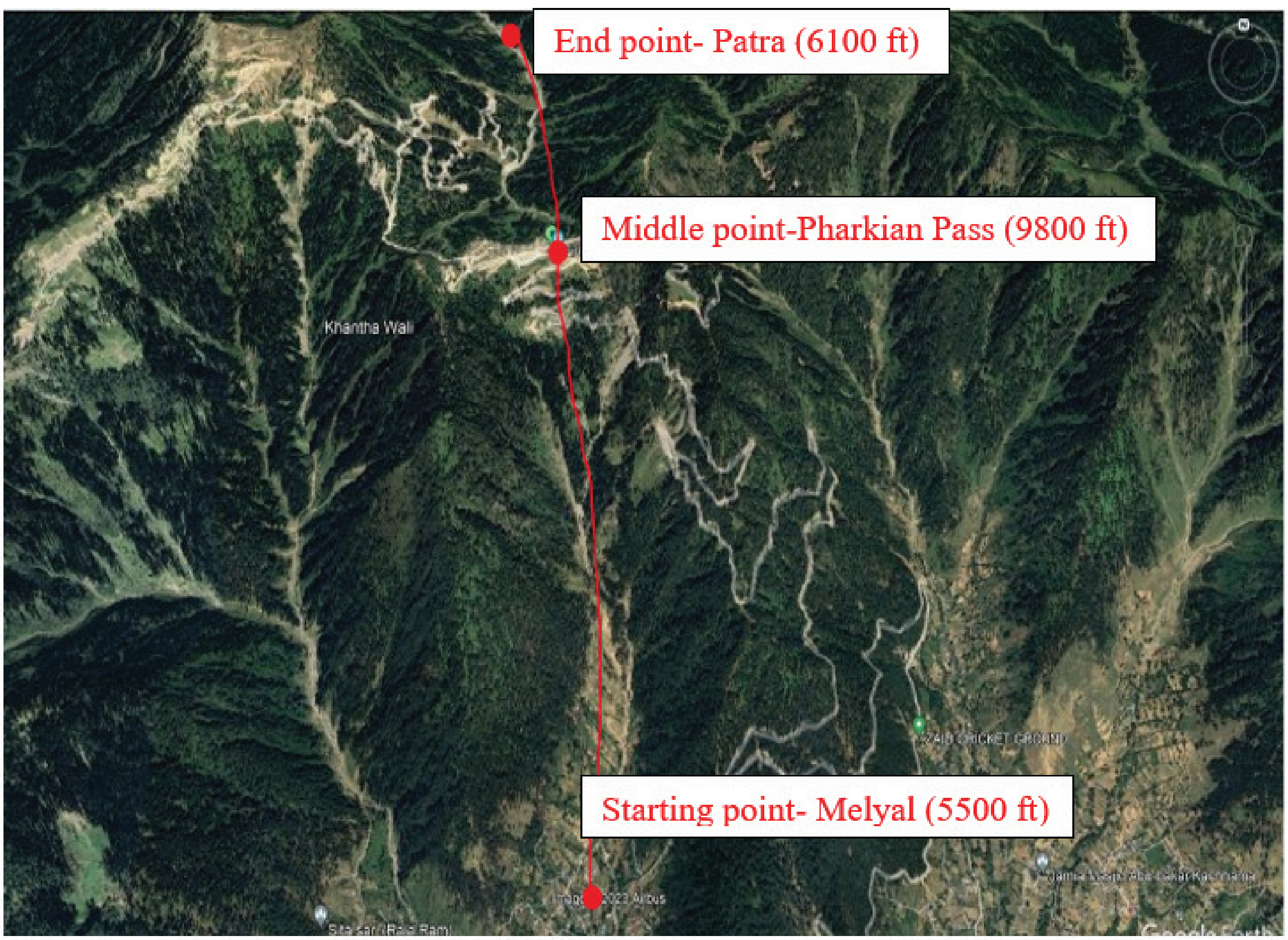

Figure 1. Proposed alignment of the aerial cableway system.

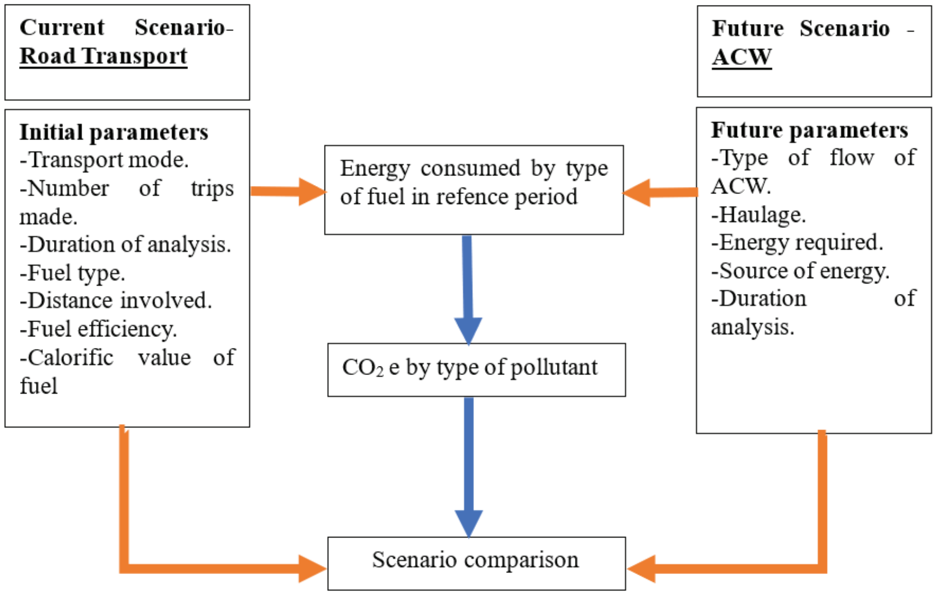

Figure 2. Environmental impact between two scenarios.

2.2 Emission Estimation

The basic essential parameters of two systems i.e transport by road and ACW under consideration can be summarised in Table 3.

Based on environmental profile of these two systems, the emissions from both scenarios would result from each of following activities shown in Fig. 2.

The emissions in the study are estimated using GHG standards (ISO 14064, 2011) and GHG protocol standards as given in (WRI,2004). The standard equation used to estimate the emission is Eqn. 1. The emission factor signifies the rate at which emissions are generated per unit of that material and are taken from IPCC inventory and recognised studies. The total emissions during the construction of ACW, based on the life cycle of material used in ACW for different phases include emissions during construction, including during the construction of platforms, by use of reinforcements, cable way and transport during execution, which works out to be 1,20,031.6 kg CO_2. The ACW operations, which run on electricity supply, emit 1,68,000 kg CO_2. Similarly, the mountainous unpaved road is resurfaced every 5 years. The carbon emissions from the same are estimated to be 4,28,744.522 kg CO_2. The emission reduction due to the shifting of 75 % of 12,000 truck trips results in 2,53,148.9 kg CO_2. The details of these calculations are in the supplementary sheet.

Table 3. Technical specifications of the scenarios

System	Parameter	Value
Transport by road	Total length	50 km
	Mean width	6 m
	Average speed	20 km/hr.
Cable way system	Total length	4.6 km
	Design Capacity	10 Tons/hr/direction
	Operation type	Single
	Monocable	carrying howling rope
	Operation mode	Continuous movement

2.3 Financial and Environmental Benefits

The benefits of the transition to ACW are analysed in two dimensions viz Economic analysis, (cost-benefit analysis of the implementation of ACW) and environmental, which evaluates carbon emissions during and after project construction.

The economic analysis is carried out for 25 years (n) with a discounting rate of 10 % (i). All the cost parameters for the CBA are estimated using the Eqn. 2 and Eqn. 3.[17]

$$Emissions = Activity * Emission\ Factor \quad (1)$$

$$Annual\ Net\ Present\ Worth = \left(\sum Benefits\ or\ Costs\right) * \frac{((1+i)^n - 1)}{i*(1+i)^n} \quad (2)$$

$$Capital\ Present\ Worth = \left(\sum Benefits\ or\ Costs\right) * \frac{1}{(1+i)^n} \quad (3)$$

The broad categories under which benefits can be summarised are benefits due to a reduction in fossil fuel consumption, benefits due to the social cost of carbon, benefits due to a reduction in external environment cost and benefits due to a drastic reduction in truck maintenance. The costs involved in the transition to ACW will involve the cost required to construct, maintenance and operation of ACW, cost of annual consumption to run ACW.

3. RESULT AND DISCUSSION

3.1 Benefits

The economic benefits of the Social Cost of Carbon (SCC) are significant. SCC represents the financial cost of climate change resulting from an additional ton of carbon dioxide emission. The range of social cost varies upon the climate variations at different locations in India, hence looking upon the climatic conditions of the study area, the value is taken as 157 US Dollars. The conversion rate of US Dollars to Rupees as of 24 August 2023 is 82.64. Hence, the social cost of carbon dioxide is estimated at Rs. 12,974.48 for one ton of carbon dioxide. As there is a significant reduction in carbon

Table 4. Detailed analysis of benefits and cost analysis

Benefits-social cost of carbon due to emission reduction					
Inputs	**Units**	**Inventory**	**Emission factor**	**Unit**	**Carbon Emissions**
Carbon Emissions reduced	tons	452.101	12,974.48	Rupees	58,65,775.38
				Total	**Rs. 58,65,775.38**
Benefits-benefits due to cost saving due to fuel					
Inputs	**Units**	**Inventory**	**Cost of Diesel**	**Reduction in trips**	**Cost saved (Rs)**
Diesel (Defence trucks)	l	1,27,659.574	85.72	75%	82,07,234.04
				Total	Rs. 82,07,234.04
Benefits- reduction of external environmental cost					
Type of Pollutant	**Local emissions from diesel trucks**	**Total emissions for 9000 km**	**Total emissions**	**The external cost of pollutant**	**Total annual cost**
Unit	**g/km**	**g**	**Tons**	**Rupees/ton**	**Rupees**
External environmental cost					
CO	4.5	40500	0.0405	33800	1368.9
HC	1.55	13950	0.01395	10400	145.08
NO_x	8.86	79740	0.07974	182000	14512.68
PM	0.49	4410	0.00441	845	3.72645
CO_2	706	6354000	6.354	279500	1775943
				Total	17,91,973.386
Cost-truck maintenance					
Inputs	**Units**	**Inventory**	**Maintenance cost**	**Unit**	**Carbon Emissions**
Truck maintenance	No. of trucks	30	10000	Rupees	3,00,000
				Total	Rs. 3,00,000
Cost-energy for the running of cableway system					
Inputs	**Units**	**Inventory**	**Emission factor**	**Unit**	**Carbon Emissions**
Energy Consumption	kWh	3,00,000	5.10	Rupees/ kWh	15,70,485.84
				Total	Rs. 15,70,485.84

emissions with the introduction of the cableway system, there is a significant saving in the SCC, estimated in the Table 4.

The significant benefits are in terms of reduction of fuel. The Annual fuel consumption for fulfilling 12000 trips for a mileage of 4.7 km/l covering 50 km was computed as 1,27,659.5745 Ltr. The cost of diesel for the State of Kashmir as of 20th August 2023 was Rupees 85.72. The annual fee for fuel is estimated at Rupees 1.0942 Crores. The reduction of trips transferred to the Aerial Cableway are expected to be 75 %, thereby saving annual costs in energy to 82.07 lakhs. The cost saving due to fossil fuel consumption is estimated in Table 4.

Benefits due to external environment costs are due to reduced air pollutants in the atmosphere. These pollutants and their emissions tend to hamper the environment. The expenses related to these damages are termed as External costs, but these costs are not directly by the producer. The following cost would be reduced as 9,000 trips are expected to be reduced.

Benefits from saving truck maintenance costs have also been factored into calculations. The moderate estimate by the manufacturer for the annual cost of maintaining trucks is approximately Rs. 10,000 trucks. An average of 30 trucks makes their trips within the study area, resulting in maintenance costs of Rs. 3,00,000.

3.2 Costs

The four major factors involved in cost analysis are capital cost, annual electricity consumption cost, annual ACW maintenance cost and road resurfacing cost incurred once in five years as seen in Table 5.

The capital cost for ACW for 4.6 km is estimated to be 10 Cr based on similar nature of project being executed by MoD, India[18]. The recurring costs primarily involve purchasing energy for the operation of ACW and the maintenance cost of the road and ACW. The annual energy consumption is estimated as 307938.4 kWh, and the electricity rate in Kashmir for projects is 5.1 Rupees/ kWh.[19]

The road's maintenance cost is considered once in five years, and the cost of different materials is considered. The annual maintenance cost for the ACW is 20 lakhs.[20]

3.3 Environment Assessment

The environmental concern is very well addressed by

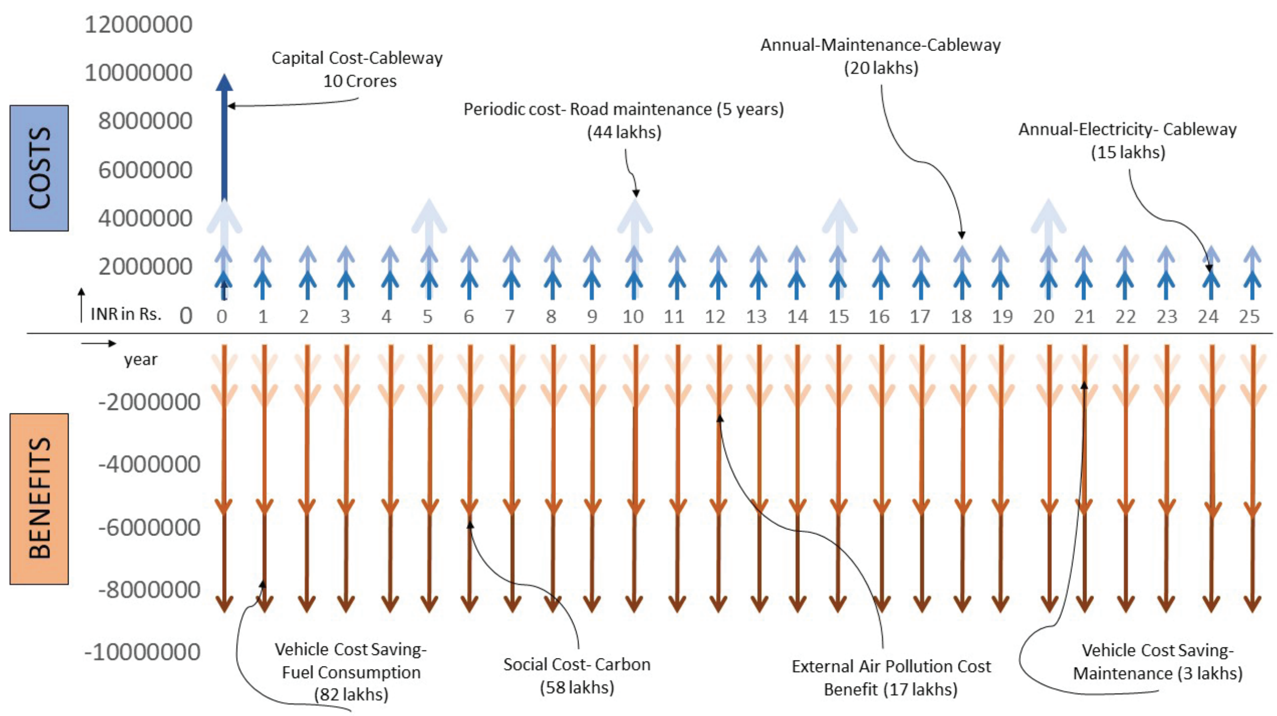

Figure 3. Cash flow diagram of benefit to cost analysis.

Table 5. Net present worth without considering capital cost

Benefits	Net present worth in Lakhs (Rs)	Costs	Net present worth in Lakhs (Rs)
Diesel trucks- maintenance	27.2311	Operations and maintenance cost of road	144.4027
Fuel consumption	744.9739	Cost of energy-operations of Aerial Cable way	142.5536
External air pollution costs	162.6581	Operations and maintenance cost for ACW	18.1541
Social cost of carbon	526.4683	Energy usage for miscellaneous work	14.2554
Total	1,461.332		319.3658

Table 6. Net present worth method considering the capital cost

Benefits	Net present worth in Lakhs	Costs	Net present worth in Lakhs
Diesel trucks- maintenance	27.2311	Capital cost for aerial cableway	1,000
Fuel consumption	744.9739	Capital cost- 5-year road resurfacing & fuel consumed	191.7047
External air pollution costs	162.6581	Energy- operations of aerial cable way	142.5536
Social cost of carbon	526.4683	Operations and maintenance cost	18.1541
-		Energy usage for miscellaneous work	14.2554
Total	**1,461.332**	**Total**	**1,366.6678**
	Net Present Worth= Benefits-Costs **= 14,61,33,150.1-13,66,66,777.2** **= Rs. 94,66,372.9** **=B/C=14,61,33,150.1/13,66,66,777.2=1.069>1** **Hence Accepted.**		

incorporating ACW. The reduced emissions are obtained by Eqn 4.

Emission reduced = (Emissions reduced from vehicle+ emissions from resurfacing of road) -(emissions from construction and operations of ACW) (4)

The emissions reduction achieved is highly significant and estimated to be 57.7 %

3.4 Cost-Benefit Analysis

As evident from Fig. 3, the optimum benefits start

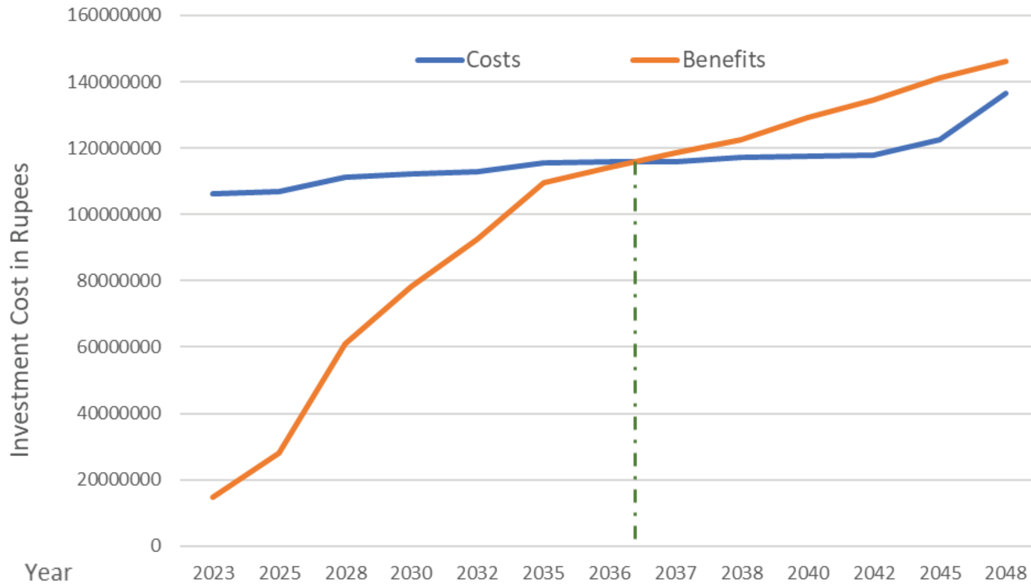

Figure 4. Break-even analysis.

resulting from the first year itself and remains constant with constant values added from saving fuel consumption, SCC, external air pollution cost and maintenance cost.

Concerning cost in the cash flow diagram, the initial investment reflected is 10 Cr. The road maintenance cost is incurred every five years. The other costs which remain constant and are incurred annually are the 'annual maintenance cost of ACW' and the cost incurred on electricity consumption every year.

3.4.1 Benefit-to-Cost Ratio

The difference between cost and benefit primarily guides the acceptability of a project.

As mandated in economic analysis, the 'Annual and capital net worth' is computed using cost/benefit (as desired) by incorporating a duration of 25 years and input factors. For the first year, n=1. Using equations mentioned in para 2.3, 'net present worth' is summarised in Table 5 and Table 6. If the net present worth of the integration of ACW for greener environment has a B/C or benefit/cost ratio greater than 1, acceptability is indicated as seen in Table 6.

3.5 Break Even Analysis

The break-even analysis involves the benefits likely to be incurred after the commissioning of ACW by weighing against the cost incurred in execution. The analysis would assist in identifying the duration after which the investment cost would be recouped.

As seen in Figure 4, ACW proves to be one of the fastest and most economical sustainable transport. In just 12 years, the break-even point is reached, indicating the cost recovery.

It deserves merit to mention that the break-even point can be achieved much earlier if the revenue generation aspect is considered. Presently, the entire analysis is environmental based.

4. CONCLUSION

The paper establishes the promising role of ACW in ensuring severe reduction of GHG emissions originating from military transport by 5.61 lakhs CO_2 equivalent emissions every year which is 57.7 %. With the holistic approach by Using the cost-benefit-based economic analysis, the paper shows that the transition of ACW has financial benefits and results in cumulative saving of 1.6 Cr from reduced fuel consumption, saving in vehicle maintenance, reduced social cost of CO_2 and reduction in air pollution cost. The other unparalleled strategic benefits include all-weather connectivity in terrain prone to avalanches and landslides. The transition to ACW will immensely reduce road accidents in the Himalayas and would also be of immensity use during the evacuation of medical casualties in hilly remote areas where roads are often prone to natural blockages. Our analysis shows that the ACW is the only promising alternative to road transport where a break-even point is expected shortly. Replication of this study across the spectrum in the mountains in Kashmir where forces have option of constructing numerous ACW deserves merit which will facilitate it in craving a vision towards 'Green Defence'.

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CONTRIBUTORS

Dr Prashant P. Bhave is working with VJTI, Mumbai. His research interests are: Water and waste water treatment, air pollution research, solid waste management, reducing carbon footprint and sustainable development.
His major contributions in the paper are: Final drafting, critical revision, and final approval of the article.

Mr Chetan Dhawad is a PhD scholar at Civil & Environment Engineering Department, VJTI, Mumbai. His research interests are: Net zero cities and reducing carbon emissions, carbon footprint
His major contributions in the paper are: Formulisation of concept and analysis of feasibility, Drafting the article, application, visit to study area for design and data collection in coordination with authorities.

Ms Vibha Jain is pursuing MTech from Environmental Engineering, Civil and Environment Engineering Department, VJTI, Mumbai. Her research interests are: Decarbonisation, carbon accounting, solid waste management.
Her contribution in the present paper are: Methodology framework design, methodology framework, data analysis, and interpretation by use of various tools.