Supporting Armed Forces Efforts Towards Sustainability: Application of Simulators in Military Training

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Acknowledgement

It's our pleasure to present the report 'Supporting Defence Sectors Efforts Towards Sustainability: Application of Simulators in Army Training', which is a first-of-its-kind research study conducted in India.

We are extremely grateful to the offices of the Chief of Defence Staff, the National Security Council Secretariat, the Integrated Defence Staff (IDS), the Army Training Command (ARTRAC) and the Army Design Bureau (ADB) for taking out their valuable time to review our research activity and their insightful comments and feedback.

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Key Findings

The application of simulators for defence training is not only relevant not only from an economic standpoint, but also has significant in respect of the emissions savings associated with it. However, the environmental benefits arising due to its application have not been studied robustly, until now. This study aims to quantify the environmental and economic benefits from using selected simulators for training in the Indian Army. Some of the key findings of the study are:

- The T-90 Driving Simulator could lead to carbon reduction of up to 1919 tonnes and 640 tonnes at the regiment and squadron level, respectively, over the assumed lifespan period of 30 years. In economic aspects, it could help in savings of INR 4.54 crore and INR 1.40 annually, at an armoured regiment and squadron level, respectively.
- The T-90 Crew Gunnery Simulator could lead to carbon reduction of up to 3676 tonnes and 1225 tonnes at regiment and squadron level, respectively over the assumed of lifespan period of 30 years. Whereas comparing in economic aspects, it could help in savings of INR 12.7 crore and INR 4.13 crore annually, at an armoured regiment and squadron level, respectively.
- The Automated Driving Simulator that is used for light four-wheel vehicle driving training could lead to carbon reduction of 103 tonnes of CO_2 eq. avoidance over its assumed life of 15 years. Whereas comparing in economic aspects, it could provide annual savings of INR 3.75 lakhs at a regiment level.
- The Advance Weapons Simulator (AWeSim) could lead to carbon reduction of 55 tonnes over a period of 10 years, whereas from an economic aspect, it can provide annual savings INR 24.60 lakhs.
- Due to the high cost of ammunition of certain sophisticated weapon systems, there are restrictions imposed on their live firing for training. Nonetheless, it is imperative to train personnel on such systems for proficiency and familiarization. Simulators (such as the Anti-Aircraft Air Defence Simulator, or “3ADS”) address this gap, while also eliminating the release of toxic gases within the atmosphere.

List of Abbreviations

3ADS	Anti-Aircraft Air Defence Simulators
4W	Four-Wheeler
APDS	Armour-piercing Discarding Sabot
APFSDS	Armour-piercing Fin-stabilized Discarding Sabot
ARTRAC	The Army Training Command
AWeSim	Advance Weapons Simulator
CAGR	Compound Annual Growth Rate
CH_4	Methane
CISR	Containerized Indoor Shooting Range
Cl	Chlorine
CO	Carbon Monoxide
CO_2 eq.	Carbon Dioxide Equivalent
CO_2	Carbon Dioxide
COP	Conference of the Parties
CTSR	Containerized Tubular Shooting Range
EME	Electrical and Mechanical Engineers
GHG	Greenhouse Gases
POF	Point of Fire
US$	US Dollars
H_2SO_4	Sulphuric Acid
HCN	Hydrogen Cyanide
HE-Frag	High-Explosive Fragmentation
HEAT	High-Explosive Anti-Tank
HFCs	Hydrofluorocarbons
CFC11	Trichlorofluoromethane
HNO_3	Nitric Acid
HQ IDS	The Headquarters of the Integrated Defence Staff
IDS	The Integrated Defence Staff
IDSA	Institute for Defense Studies and Analyses
NDC	Nationally Determined Contributions
GDP	Gross Domestic Product
SOP	Standard Operating Procedure

INR	Indian Rupee
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilograms
km	Kilometres
KVA	Kilovolt-amps
L-V	Live and Virtual
LMG	Light Machine Gun
mm	Millimetres
MMG	Medium Machine Gun
N_2O	Nitrous Oxide
NF_3	Nitrogen Trifluoride
NOx	Nitrogen Oxides
NSA	National Security Advisor
OEM	Original Equipment Manufacturer
PDV	Present Discounted Value
PFCs	Perfluorocarbons
SF_6	Sulphur Hexafluoride
PO_4^{-3}	Phosphate Ion
POL	Petroleum, Oil, and Lubricants
SAM	Surface-to-Air Missile
MANPADS/MPADS	Man-Portable Air-Defence Systems
SOx	Sulphur Oxides
T90 CGS	T-90 Crew Gunnery Simulator
T90 DS	T-90 Driving simulator
TERI	The Energy and Resources Institute
PAF	Platelet-activating Factor
SO_2	Sulphur Dioxide
UAVs	Unmanned Aerial Vehicles
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America

1. Introduction

Climate change is a pressing concern, needing urgent action. The threats from climate change have been growing and its disastrous impact is becoming evident, with an increase in the frequency and scope of natural, climate-linked disasters. The nature of the problem is unique, the impact is all encompassing and the risks to both infrastructure and human life are high.

Synthesis of the IPCC's 6th Assessment Report released in March 2023 (IPCC, 2023), spells out climate change's disastrous consequences on the environment in the coming decades. It also underscores the urgency of taking more ambitious action and, if nations act now, the world still has a chance to secure a liveable and sustainable future for all.

To tackle climate change and its negative impacts, the world leaders at the UN Climate Change Conference (COP21) in Paris reached a breakthrough on December 12, 2015: (popularly known as the historic Paris Agreement). The Agreement sets long-term goals to guide all nations to substantially reduce global greenhouse gas (GHG) emissions in order to to limit the global temperature rise in this century to 2 degrees Celsius, while continuing efforts to further limit the rise within 1.5 degrees. Countries' commitments are reviewed every five years and financing support to developing countries to mitigate climate change, strengthen resilience and enhance abilities to adapt to climate impacts are provided under the agreement. (UNFCCC, 2015).

While the goal of the defence sector is ensuring national protection, however rising GHG contribution in defence operations require corrective actions that can decarbonize the sector. Global defence industry's contribution to worldwide CO2 emissions can increase from its current level of 2% to 25% by 2050 (Dimitrova et al., 2021).

From a financial standpoint, the military sector is one of the largest spenders in the world. In 2020, global military expenditure touched $2 trillion (Cottrell, 2021), which is almost the equivalent of GDP of several developed countries such as Canada, Italy and South Korea. Thus, given the magnitude of its operations, it is imperative that the global military industry adopts strategic initiatives focused on reducing its carbon footprint.

Climate change is gaining traction as a 'threat multiplier', exacerbating security threats/risks, especially in conflict scenarios. The national security implications of climate change impacts are far-reaching. Its consequences will likely foster political instability which is already a known driver of small-scale conflicts and human security issues (Adger et al., 2014), interstate wars and catastrophic humanitarian disasters. Apart from the impact on society, an increase in the frequency and intensity of extreme weather events directly impacts military assets and undermines military readiness. Droughts, excessive rainfall and extreme temperatures can threaten many training activities, and the environment for military operations may be constrained or altered in the long run. The Union of Concerned Scientists, in its report 'The

US Military on the Front Lines of Rising Seas' highlighted the direct impact of climate change on the military which included the risk of "losing land where vital infrastructure, training and testing grounds, and housing for thousands of its personnel currently exist".

1.1 Global and National Military Initiatives

Recognizing the growing impact of climate change, some countries over the last few years have adopted the principles of climate change within their 'National Defence Strategy'. The United States of America in 2021 stated that it will take appropriate policy actions to prioritize climate change considerations as part of its defence and security strategy (Mehta, 2021). Additionally, the French Ministry for the Armed Forces in 2022 developed a comprehensive "Climate & Defence" policy, drastically rejigging its military. The strategy is based on strengthening the Ministry's organization in terms of knowledge and anticipation of strategic climate change issues and the implementation of an ambitious adaptation policy by all the armed forces, directorates and departments. In 2021, the United Kingdom's Ministry of Defence strengthened its approach towards mitigating the aspect of climate change by transitioning to renewables and rolling out an electric vehicle fleet for its operations (MoD, 2021).

The Indian military has also just begun to examine the implications of climate change on its military tactics, operations, and strategy. The Joint Doctrine of the Indian Armed Forces acknowledges that the "environment has emerged as a critical area of the security paradigm" (Integrated Defence Staff, 2017) and cites several non-traditional security problems related to the environment. The Indian military is taking initiatives across the country to enhance its sustainability and efficiency, by incorporating the usage of renewable energy in its operations. In 2021, Indian Army inaugurated the First Green Solar Energy harnessing plant of 56 kVA using Vanadium based battery technology in North Sikkim, at an altitude of 16,000 ft for its troops in the region (Singh, 2021). Similarly, at the 2016 International Fleet Review, the Indian Navy debuted its first warship powered completely by biofuel, and it is in the process of modernizing its blue-water capabilities to attain a zero-carbon footprint (Jayaram, 2018). Similarly, the Indian Air Force is undertaking trials on usage of biofuels in military aircrafts, as aviation sector is considered the largest contributor of CO_2 emissions. While these efforts showcase the growing awareness and adoption of the concept of sustainability and climate change by the Indian military, its pace of development needs to increase rapidly.

1.2 Incorporation of Simulators: Improving Training Capabilities and Battling Climate Change

In 2009, the Institute for Defense Studies and Analyses (IDSA) Working Group on Security Implications of Climate Change for India identified India's key vulnerabilities and highlighted the possible adverse impact on the strategy and tactics of the Indian armed forces. Climatizing moves among the military are on the rise due to several reasons including impacts of climate change on military activities. For instance, the melting of Siachen glacier could force the Indian military to change its strategy in the region.

The report *Climate Change and National Security: Preparing India for New Conflict Scenarios* (The Indian National Interest Policy Brief, 2008), concluded that "India needs to develop military capabilities to address a range of new strategic scenarios including climate change". Climate risk requires flexibility, adaptability and incorporation of multi-functionality in the role and capability of the armed forces. New emerging technological solutions must be explored to address the potential environmental implications. There are multiple mitigation strategies that need to be considered, including energy efficient defence equipment, transition to sustainable fuels and leveraging options for sustainable ways of imparting training.

While transition to fuel efficient technologies and sustainable fuels have found some attention in discourses around climate change mitigation in defence, the role of climate friendly training options has not caught the same level of attention. From infantry weapons to air defence systems and tanks to fighter jets, simulators play a critical role in providing training to military personnel in realistic surroundings. They generate near real responses to various situations at a fraction of the real time training costs.

The discussion and thinking in the Indian military have hitherto focused on the efficiency gains and cost savings associated with using simulators for training, however, the environmental benefits linked to the use of simulators in defence training has not been taken into cognizance so far. For example, a simulator has the potential to eliminate the consumption of scarce fossil fuels while mitigating carbon emissions released during their combustion. GHGs trap heat in our atmosphere, causing global warming. At the national level, coal accounts for the largest share of emission at 66%, followed by oil at 22%. Further, the ammunition fired during training also has an environmental impact both during its manufacture and firing. While, it is acknowledged that defence personnel need to undergo a minimum amount of training using live ammunition, it is hypothesized that there are significant benefits when a substantial share of the training is moved to virtual platforms, which eventually will lead to lesser requirement of ammunition as well as fossil fuel consumption. This trend is in fact seen in the US and Europe.

Although efforts are on to decarbonize the power generation by shifting to renewable energy sources, as well as electrification of the transportation sector, sustainability initiatives in the defence sector, including adoption of simulators, will demonstrate a strong intent to support India's ambition to decarbonize the economy. As per the updated Nationally Determined Contributions (NDCs), India stands committed to reduce emissions intensity of its GDP from the 2005 level by 45% and achieve about 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. Further, India has committed to be carbon neutral by 2070 (MoEFCC, 2022).

The advantages of simulations, especially in training, are manifold. Simulations save time and money (on both capital and revenue expenses) and wear & tear of expensive and sophisticated equipment. On the capital head, the savings accrue from reduced use of real equipment, thereby extending its life and thus, replacement. On the revenue side, savings arise from reduced logistics costs, consumption of costly ammunition and fuel and maintenance costs. Simulators can create near real life learning experience, whereby skills, process, and knowledge can all be enhanced; while personnel can afford the luxury to explore, experiment, and repeatedly apply this knowledge to unlimited modelled scenarios and situations. Touted as the most versatile form of learning available, computerized simulations make training more efficient and effective than ever. Finally, while aiming at improving the skills, knowledge, and experience of the individual handler/decision-maker dramatically, they, at the same time, permit mistakes during training without any safety or economic implications. Safety is perhaps the most important advantage of using simulators. Simulator usage prevents accidents that occur on the training field. Between 2006 and 2018, 31.9% of all deaths in the US armed forces occurred during on-field training, while only 16.3% happened during combat (Zachary Cohen, 2019). All-weather training is another crucial advantage of simulators. In addition, simulations are also useful in trial evaluation of new generation weapons/equipment and help in truly depicting their worth in all modelled scenarios, thus enabling smart acquisitions. These benefits of simulators not only provide a skilled training opportunity to the individual but also helps in building confidence and "muscle memory" so that when an individual is trained on on-field equipment, one is able to judiciously utilize their skills and time.

1.3 Framework for Simulators in Armed Forces 2021

While almost one-third of the Indian army is deployed in guarding the frontiers and in counter-terrorism operations, the balance two-thirds is involved full-time and comprehensively in training related activities. However, these training activities today stand constrained by budgetary limitations and the increasing effect of climate change. Rapidly shrinking training areas and firing ranges due to exponential urbanization and population increase are also one of the reasons for reduced training activities.

Recognizing the enormous potential of simulators, India's Ministry of Defence introduced the "Framework for Simulators in Armed Forces" in 2021 for enhanced utilization of simulators by armed forces to impart safe and cost-effective training. The framework acknowledges the increasing resource and budgetary constraints of the armed forces and states that *"The significance of simulators is well understood by the Armed Forces in terms of cost reduction, safety, training in near realistic setting by replicating variable combat scenarios, quicker training and conserving the critical operational equipment from wear and tear. However, a need exists to optimize exploitation of simulators in the Armed Forces and Indian Coast Guard. Hence, a comprehensive framework has been formulated."* The aim of the policy is to transform to simulation-based training across all military domains for combatants, leaders, maintainers, administrators and life science experts. While focusing on indigenous design and development to achieve cost-effective, safe and smart training, the framework further aims to inculcate efficient training capacities, whilst also preserving the life of the on-field equipment and reducing the overall expenditure.

The framework mandates primarily the Services Headquarters and the Headquarters of the Integrated Defence Staff (HQ IDS) to identify areas where simulators can be used and to develop road maps and SOPs. It is understood that while considerable progress has been made in developing the policies, implementation is still a work-in-progress. Moreover, it is also important to note that the framework stops short of highlighting the environmental benefits that may be associated with such a transition. According to the Indian Army's training philosophy, "The essence of training in the Indian Army is such that no soldier or officer should ever lose his life or limb in combat, because he was inadequately trained." Moreover, since almost all Simulators work on a technology platform, they are amenable to enormous performance enhancement using Artificial Intelligence (AI) and Machine Learning (ML). Largescale simulator usage will not only abide by the principles of the Indian Army but will also help in the development of sustainable warfare management.

1.4 Looking Ahead

As the discussion of the military's contribution to climate change mitigation proceeds, it is crucial to embed it within India's overall national security objectives. Efforts must be made to ensure that military operations adhere to sustainability principles without compromising the overarching objective of defence preparedness and effectiveness. Additionally, new, emerging and existing technological solutions must be explored to enhance effectiveness and address the potential environmental implications through carbon emission reduction and contribution to the carbon market. Hence, it is imperative that modern techniques like enhancing the use of simulators in defence training and AI and ML are utilized extensively to ensure that training can be carried out both effectively and efficiently.

Critical on-field arms and ammunition of the Indian Army account for more than half of the total defence budget of India, which is the third highest in the world after the USA and China. To ensure optimal utilization of defence budgets, it is essential to explore new technological approaches and concepts. Primarily the focus should be on those that guarantee increased efficiency and return on investments, while parallelly addressing and contributing to tackling the issues of country's environmental concerns. Hence, acknowledging prevailing realities of numerous complex security challenges, the Indian Armed Forces must systematically increase usage of simulators. Enhancing defence training on simulators captures a plethora of benefits without compromising on efficiency while concurrently also addressing climate issues.

1.5 About the Study

TERI has undertaken this study as part of its overall objectives to enhance environmental awareness and promote sustainability. It has drawn support from ZEN Technologies Limited (hereinafter ZEN) as well as subject matter experts, including end users of simulators and industry players. It is learnt that Zen is currently integrating AI and ML into its products to bring enhanced technological solutions to the customers. This study seeks to assess and quantify the environmental and economic benefits of using simulators for training in armed forces. Drawing upon TERI's vast experience and expertise, the study seeks to identify the potential for the defence sector to contribute to the "green goals" of the nation and to be environmentally sustainable, without compromising on national security. Our hypothesis is that while not completely replacing live equipment for training personnel, simulators bring the following key sustainability benefits:

- Reducing emissions and the environmental impacts through reduced consumption of fossil fuels such as petrol and diesel, as well as material extraction and processing for manufacturing ammunition used in training.
- Cost savings – in ammunition, POL, maintenance through reduced wear and tear of the equipment, replacement costs as its life gets prolonged and logistics
- Saving time and greatly improving the safety, efficiency, quality, and effectiveness of training.

2. Approach and Methodology

2.1 Understanding Various Simulations

Simulations exist in many different forms, with varying degrees of realism. It is extremely important for a military planner to understand the types of simulations because only then can one plan correct and optimum development and deployment of the same.

Literature review and interaction with subject matter experts reveals that there exists three types of simulations in military training – live simulations, virtual simulations and constructive simulations.

- **Live Simulations:** These are simulations where actual real-life players use original systems in a real and physical environment, and only the effect of the activities is simulated. These typically involve humans and/or equipment activity in a setting where they would operate for real. They are considered simulations because they are not conducted against a live enemy.
- **Virtual Simulations:** These are simulations involving humans and/or equipment where actual players use simulation systems in a computer generated synthetic or virtual environment. The running time can be real or in discrete steps, allowing users to concentrate on the key training objective. These represent a specific category of devices that utilize simulation equipment (which exactly replicates the controls of the original equipment) to create a simulated world for the user. In this manner, the system can accept input from the user (e.g., body tracking, voice/sound recognition, physical controllers) and produce output to the user (e.g., visual display, aural display). Simulations use the aforementioned modes of interaction to produce a sense of immersion for the user, for instance, a tank, vehicle and flight simulator.
- **Constructive Simulations:** A constructive simulation includes simulated people operating simulated systems. Real people stimulate (make inputs) to such simulations but are not involved in determining the outcomes. A constructive simulation is a computer programme. For example, a military user may input data instructing a unit to move and to engage an enemy target. The constructive simulation determines the speed of movement, the effect of the engagement with the enemy and any battle damage that may occur (Department of Defense USA, 2011).

As can be made out, the Live and Virtual (L-V) simulations primarily aim at perfecting the 'weapon/ equipment/systems handling skills' of the trainee; whereas the Constructive Simulations aim at improving and refining the decision-making capabilities of the commanders and staff officers.

2.2 Technology Selection for Assessment of Net Benefits from Use of Training Simulators

Based on a close evaluation/scrutiny of literatures, the scope for usage of simulations in training spans the entire gamut from sharpening individual skills to collective usage of a system (i.e., crew training) and for training of the decision-makers. An indicative list of potential crew training requirements has been drawn and is presented in Table 1.

Table 1: Training for Specialized Individual/Crew Skills: Specific Arms/Services

Category	Types	Service	Remarks
Weapons	Small arms (personal weapons)	All Services	All personnel of all arms need to be proficient in handling their personal weapons
	Heavy, crew served weapons	Specific to each Service	Examples: Training of MMG/LMG/AK47/ mortars for infantry. Anti-aircraft guns in the Corps of Air Defence
Equipment	All types	Specific to each Service	Examples: Training of Mine laying and recovering parties Bridge launching parties in Bridging Engineer Regiments Vehicle/equipment repairing on its assembly line for Electrical and Mechanical Engineers (EME)
Driving	**Light vehicles**	**All Services**	
	Specialist vehicles (including Class A vehicles)	Specific Services	Each Arm and Service (e.g., armoured corps, mechanized infantry, artillery, signals, engineers, air defence, EME, etc) has its specialized vehicles, having a requirement for its crew to operate the vehicle in synchronization
Maintenance of Weapons, Equipment and Vehicles	Basic	For all Services	Important for learning the same on simulations so as to limit the rigours of wear and tear during training for maintenance on original weapons, equipment and vehicles
	Advanced	Predominantly Electronics and Mechanical Engineering	

Source: Chauhan, 2013

In the defence services, simulators are used extensively in training. The Indian Army uses simulators for different arms and services for basic, advanced and tactical training. In this study, we have selected some of the **simulators,** as listed below, to assess the sustainability benefits linked to their usage in defence training.

- Armoured Vehicle Simulator
    - » T-90 Driving Simulator (T-90 DS)
    - » T-90 Crew & Gunnery Simulator (T-90 CGS)
- Automated Light Vehicle Driving Simulator (ADS)
- Virtual Range – Advanced Weapons Simulator (AWeSim)
- Anti-Aircraft Air Defence Simulator (3ADS)
- Live Range – Containerized Tubular Shooting Range (CTSR)

The data linked to the operational parameters of the simulators including costs, has been collected from open sources as well as select simulator OEMs.

2.3 Defining the Broad Objective of Assessment

The objective of the exercise is to assess and quantify sustainability benefits, both environmental and economic, linked to simulator usage in army training. The environment and the economic dimensions form two of the three major pillars of sustainable development framework as outlined in the report of the 'World Commission on Environment and Development, Our Common Future'.

2.3.1. Environmental analysis

Training sites often have high levels of heavy metal and explosive residues left by live ammunition usage. The major residues include energetic and metallic materials from explosives and bullets respectively. Also, firing of small calibre ammunition releases lead that progressively dissolves and forms various oxides. Other metals such as chromium, arsenic, cadmium, copper, mercury, nickel, zinc get released into the soil. Energetic materials are the other source of contamination on account of live ammunition, which have high soil persistence that contaminates groundwater or accumulates in edible plants and animals. Thus, a holistic environmental impact assessment of live military training must incorporate these impacts beyond just GHG emissions.

On-field training also requires the use of fossil fuels like petrol and diesel which have their origin from carbon intensive sources. The process of oil refining involves a series of steps that includes separation and blending of petroleum products. Conversion of crude oil to petroleum products is energy intensive and is associated with emissions in the environment. Further, their transportation to fueling stations and firing ranges and training sites in heavy-duty vehicles with very low fuel efficiency, further adds to the total emissions. These emissions will be in the form of long-lived pollutants (having climate change potential) like greenhouse gases (mostly consisting of carbon dioxide and methane) as well as local pollutants like particulate matter where impacts are localized and largely affects human health.

Based on the potential environmental threats posed, the seven environmental impact categories are assessed in this study for capturing the environmental impacts arising from the use of fossil fuels and ammunition, which can be avoided through use of simulators for training. The impact categories include global warming potential, acidification, eutrophication, ozone depletion, human toxicity both carcinogenic and non-carcinogenic and ecotoxicity.

1. **Global Warming Potential (GWP)** measured in kg CO_2 eq. is the most used parameter to assess the climate change potential of emissions. The GWP refers to the amount of energy that 1 tonne of the gas will absorb over a given period of time, relative to the emissions of equivalent carbon dioxide (CO_2).

2. **Acidification** (kg SO_2 eq.) of soils and water mainly occurs through conversion of air pollutants such as SO_2, NO_2 into acids such as H_2SO_4, HNO_3. These acids change the soil and water's chemical properties, causes ecosystem nutrient imbalance, and increase solubility of metals into soils and corrode calcium carbonate rocks like limestone.

3. **Eutrophication** (kg PO_4^{-3} eq.) is progressive enrichment of water bodies with minerals and nutrients particularly nitrogen and phosphorus released into nature. These usually reach water bodies through leaching into ground water or by direct runoff from land. This can unbalance the ecosystem by excessive algal production starving fish and other aquatic life of precious dissolved oxygen.

4. **Ozone depletion** (kgCFC11 eq.) is from the release of chlorine and bromine molecules that interact with the ozone layer in stratosphere thus allowing more harmful UVB radiation to reach surface affecting human and animal health.

5. **Human toxicity (carcinogenic and non-carcinogenic)** and **Ecotoxicity** measured in no. of cases and PAF respectively refers to combination of outcomes like environmental persistence, accumulation in the food chain and toxicity reactions of a chemical.

The above seven impact categories of live training are on account of the various metallic and energetic emissions during manufacturing of ammunition as well as its firing and detonation. It is important to mention that life cycle assessment of selected stages of ammunition and fuels have been arrived at based on data provided in the Ecoinvent database, as well as selected literatures where impact assessment particularly for ammunition type, material composition and their impacts have been reported. Suitable ammunition has been considered that best reflects their usage in weapons used for training captured in the present analysis.

As stated in the previous section, this Study's assessment also covers the economic benefits of transitioning to simulation-based training in the defence sector.

2.3.2. Parameters identified for economic analysis

The key parameters used to estimate the economic benefits and costs are listed below: -

- Capital Expenditure
- Operational Expenditure

    - Fuel Consumption
    - Maintenance – Transportation; Equipment Repair
    - Logistics – Training Days, Manpower Support, and Other Infrastructure Requirements.
    - Ammunition Costs
    - Other Costs (Armaments, Weapons Repairs – Wear and Tear costs)
- Environmental Cost – GHG Emissions

Apart from the parameters defined under Section 2.3.1 and 2.3.2, assessment in terms of other qualitative parameters has also been discussed in this report. These include training efficiency, measured in terms of skill improvement (better preparedness), time management and safety.

2.4 Overall Approach for Sustainability Assessment

The overall approach of the exercise was to first understand the current level of specific training requirements of defence personnel and the extent to which these can be shifted to the shortlisted simulators as presented in Section 2.2. Based on extensive interactions with concerned stakeholders, review of literature and appropriate assumptions, data related to performance consumption of fossil fuels, ammunition, and material composition of the ammunition was collated. Further, to capture the economic the dimensions of the sustainability pillar, the relevant equipment and user costs were considered for on-field training equipment and simulators including their life in years, maintenance schedule and costs. Finally, net avoided environmental and economic costs from the use of simulators was estimated and simulators usage scenarios developed to capture the benefits under different scenarios.

3. Assessing Benefits and Costs of On-field T-90 Tank vs T-90 Simulators

The T-90 Tank originally made in Russia is amongst the most powerful main battle tanks in the world. It is a third-generation tank, a direct successor of T-72, with a 125 mm 2A46 smoothbore main gun, the 1A45T fire-control system, an upgraded engine, and gunner's thermal sight. It includes lethal Armour Piercing Fin Stabilized Discarding Sabot (APFSDS) and barrel launched INVAR Anti-tank Guided Missiles. The gunner is also provided with the 1G46 day sighting system which includes a laser range finder, missile guidance channel and allows tank-sized targets to be detected and engaged at 5 to 8 kilometres (3.1 to 5.0 miles).

This chapter presents environmental impacts and monetized estimates as well as the net economic costs arising from on-field driving and gunnery training and the extent of avoidance of costs that can be achieved if the same is imparted on simulators to the extent possible that the right balance of virtual and on-field training is achieved.

3.1 Assumptions for Estimation of Avoided Cost Arising from Transition of On-field Training to Simulators

3.1.1 Transition to driving simulators

A total distance allotted to a training tank for driving in a year is 500 km. For the purpose of calculation, of this the distance allotted for training is 20% (i.e., 100 km) is assumed to be shifted to a simulator. For the ease of calculation, similar distance is assumed to be shifted from operational tanks. In an Armoured Regiment, a total of 45 tanks are assumed to be made available for authorized training purposes. Thus, the total distance of driving training that can be imparted on a simulator in an armoured regiment in a year is 4500 km, or 1500 km per armoured squadron.

3.1.2 Transition to crew gunnery simulators

An armoured regiment may have limited ammunition allocation for Crew Gunnery training. T-90 Tank fires different kinds of ammunition, ranging from Armour Piercing Discarding Sabot (APDS), High-Explosive Anti-Tank (HEAT), High-Explosive Fragmentation (HE-Frag) from the main gun and 12.7 mm and 7.62 mm ammunition from the anti-aircraft and co-axial machine guns. Due to various reasons, some of them are restricted for training purpose. However, it is crucial for the crew to practice all types of ammunition and therefore the use of simulator becomes even more important for training. For the presented avoided cost assessment, a total of 20 rounds per tank is assumed to be shifted to simulator. It is assumed 50% of the rounds are fired in a static position, and the remaining are fired on the move. In total, 900 rounds per armoured regiment or 300 rounds per armoured squadron per year are considered and accordingly, these rounds have been divided equally.

3.1.3 Assumptions linked to estimation of environmental impact for driving and crew gunnery training arising from diesel consumption

The environmental impacts linked to T-90 driving training arise from consumption of diesel. Diesel is used for running T-90 tanks and the environmental impacts of diesel production and usage is a significant contributor to total environmental burden of using T-90 tanks for training. The environmental impact linked to diesel usage is divided in two parts (i) well to tank (i.e., extraction, transportation and processing of crude oil) and (ii) tank to wheel (that includes emission arising from combustion during T-90 engine ignition).

Greenhouse gases include emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), industrial gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). All these gases lead to global warming and is measured in kg CO_2 eq. Along with GHG emissions, other environmental categories are considered for diesel production. However, due to lack of data, only GHG impact of tailpipe emissions is considered.

The environmental impact linked to production and use-phase of 1 litre of diesel is presented in Table 2.

Table 2: Environmental Impacts associated with per litre of diesel production and usage.

	Global Warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4^{-3} eq.)	Ozone depletion (kg CFC11 eq.)	Human toxicity, carcinogenic (cases)	Human toxicity, non carcinogenic (cases)	Ecotoxicity (PAF)
Upstream	0.46	0.0038	7.53E-06	7.68E-07	2.67E-09	3.88E-08	127.42
Tailpipe	2.7	0	0	0	0	0	0
Total	3.16	0.0038	7.53E-06	7.68E-07	2.67E-09	3.88E-08	127.42

Source: TERI analysis

The average fuel consumption per km in a tank for training on the move is assumed to be 4.5 litres. At the tailpipe, diesel combustion is estimated to release 2.7 kg CO_2 eq./litre. Therefore, the total emission arising from per litre of diesel combustion is 3.16 kg CO_2 eq./litre. Finally, to cover a distance of 1 km the total life cycle GHG emission (well to tank and tank to wheel) is calculated at (4.5*3.16) = 14.22 kg CO_2 eq. If a total distance of 100 km covered is migrated to simulators, then the total emission reduction potential per tank, per annum, is 1422 kg CO_2 eq. The corresponding diesel savings per tank per annum that can be achieved will be 450 litres. Whereas, the other environmental burden associated with 450 litres of diesel consumption while driving training is presented in Table 3.

Table 3: Environmental burden associated with 450 litres of diesel

	Global Warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4^{-3} eq.)	Ozone depletion (kg CFC11 eq.)	Human toxicity, carcinogenic (cases)	Human toxicity, non-carcinogenic (cases)	Ecotoxicity (PAF)
Total impact	1422	1.71	0.0034	0.00035	0.00000012	0.000017	57339

Source: TERI analysis

For crew gunnery training, a total of 20 rounds are assumed to be shifted to simulator as presented in the previous section. Of this, 10 are assumed to be fired on the move while the remaining 10 are fired in static mode. For each shot fired on the move, fuel consumption is assumed to be equivalent to the distance coverage of 2 km with an average fuel consumption of 4.5 litres/km. Hence, a total consumption of (10*2*4.5 = 90) litres of diesel takes place for shots on the move in a year.

Each static shot requires 20 mins shooting time, therefore for 10 shots, 3 hours 20 minutes of training is required. For every hour of static gunnery practice, fuel consumption is assumed to be 26.5 litres. Thus, for 3 hours 20 minutes (i.e., for 10 static shots), total fuel consumption is 88.33 litres.

If the crew gunnery training is transitioned to simulators, then the total avoided diesel consumption arising from static and on the move field training for crew gunnery per annum is estimated (90 litres + 88.33 litres) = 178.33 litres. Since the life cycle emission per litre is 3.16 kg CO_2 eq., hence the total avoided emissions are 563.52 kg CO_2 eq. per annum. The other environmental burden associated with total diesel consumption is given in Table 4.

Table 4: Environmental burden associated with 178 litres of diesel

	Global Warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4^{-3} eq.)	Ozone depletion (kg CFC11 eq.)	Human toxicity, carcinogenic (cases)	Human toxicity, non-carcinogenic (cases)	Ecotoxicity (PAF)
Total impact	563.5	0.68	0.00134	0.00014	0.0000005	0.0000007	22712

Source: TERI analysis

3.1.4 Assumptions linked to estimation of environmental impact for driving and crew gunnery training arising from ammunition usage

Live-fire training has extreme negative impacts on the environment, which are often not emphasized enough. Military preparedness and training involve better building and sustaining large forces of manpower as well as equipment which consumes vast amounts of resources. These might be common metals or rare earth elements, water or hydrocarbons. The T-90 tanks are armoured military vehicles that require energy for their operation; and that energy comes from fossil fuels. As mentioned above, the fuel economy of military tanks is extremely low at 4.5 litres/km. Live training of T-90 tanks requires large stretches of land to set up base and other facilities. These involve additional environmental burden associated with the infrastructure needs to house multiple tanks. Live training of tanks also has the need for transportation of troops to the training site which leads to additional environmental burden.

The T-90 tank is used to fire several categories of ammunition starting from small arms to large calibre kinetic kill and chemical grade weapons. Live training firing of these ammunition creates emissions; disruption to landscapes, terrestrial and marine habitats; and creates chemical and noise pollution in the surrounding areas.

The harmful environmental impacts associated with field training can be eliminated by using simulators. However, this transition can be encouraged and justified only when the environmental benefits can be quantified, and the transition is cost effective.

The scope of the quantitative environmental assessment is limited to assessing the environmental impact of the chosen product categories and not the soil and water contamination rate. It is difficult to connect mass deposition rates with specific ammunition or military activities. The contamination also depends on the period of training and type of equipment used on a training range. Moreover, no specific live range or training site was the reference chosen for this study. We have, therefore, omitted these from the scope of this exercise. The methodology used is partly ReCiPe 2016 and UseTox as suggested by peer-reviewed literature.

The production and use phase of ammunition is considered while assembly phase is left out of the scope due to lack of data (energy consumption). The production phase consists mainly of impacts associated with production of raw materials (both energetic and non-energetic components) while use phase consists of emissions from combustion of the propellant (during firing) and detonation of the warhead. The transportation emissions between two life cycle stages (i.e., manufacture and firing) and metal leaching associated with the projectile after firing is not part of the system boundary and have not been considered.

The environmental burden associated with 1 kg of energetic and non-energetic material is given in Annexure 1. The composition of a generic large ammunition, which is taken as reference is given in Annexure 2. The Point of Fire (POF) and detonation emissions of a generic large calibre ammunition is given in Annexure 3.

The manufacturing, POF and detonation impacts of a 125 mm HEAT smoothbore ammunition is presented in Table 5.

Table 5: Manufacturing, POF and detonation burden of a 125 mm HEAT smoothbore ammunition

Impact category	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC11 eq.	Cases	Cases	PAF
Manufacturing	1.05E+02	4.95E-01	2.99E-02	3.04E-05	4.36E-06	3.52E-05	4.72E+04
POF	2.74	0.000536592	0	0	3.31E-09	7.34E-09	0.000839
Detonations	0.191	0.0008292	0	0	7.34E-08	1.74E-05	194.484
Total	1.08E+02	4.96E-01	2.99E-02	3.04E-05	4.44E-06	5.26E-05	4.74E+04

Source: TERI analysis

For crew gunnery training, a total of 20 shots are assumed to be allocated as presented in the previous section. Of this, 10 are assumed to be fired on the move while the remaining 10 are fired on static mode. Considering a total of 20 rounds of fire using HEAT smoothbore gun, the comprehensive environmental impact burden avoided on switching to simulators for crew gunnery training is given in Table 6.

Table 6: Total environmental burden from a HEAT smoothbore ammunition on 20 shots

Impact category	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC11 eq	Cases	Cases	PAF
Quantity	2160	9.92	0.6	0.0006	0.00009	0.000105	948000

Source: TERI analysis

Therefore, total environmental burden including fuel and ammunition from T-90 driving as well as crew gunnery training that can be entirely avoided on switching to simulated training in a year or over the lifetime (30 years) is given in Table 7.

Table 7: Total environmental burden (ammunition and fuel) associated with T-90 driving crew gunnery training

	Global Warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4^{-3} eq.)	Ozone depletion (kg CFC11 eq.)	Human toxicity, carcinogenic (cases)	Human toxicity, non-carcinogenic (cases)	Ecotoxicity (PAF)
T-90 driving per year	1422	1.71	0.0034	0.00035	0.00000012	0.000017	57339
T-90 driving over the lifetime	42660	51.3	0.102	0.0105	0.0000036	0.00051	1720170
T-90 crew gunnery per year	2723.3	10.6	0.6	0.0008	0.00009	0.0011	970712
T-90 crew gunnery over the lifetime	816999	318	18	0.024	0.0027	0.033	29121360

Source: TERI analysis

A price on carbon helps shift the burden for the damage from GHG emissions back to those who are responsible for it and who can avoid it. Carbon pricing is an instrument that captures the external costs of GHG emissions—the costs of emissions that the public pays for, such as damage to crops, health care costs from heat waves and droughts, and loss of property from flooding and sea level rise—and ties them to their sources through a price, usually in the form of a price on the carbon dioxide emitted. Instead of dictating who should reduce emissions where and how, a carbon price provides an economic signal to emitters, and allows them to decide to either transform their activities and lower their emissions or continue emitting and paying for their emissions. In this way, the overall environmental goal is achieved in the most flexible and cost-efficient way to society. Placing an adequate price on GHG emissions is of fundamental relevance to internalize the external cost of climate change in the broadest possible range of economic decision making and in setting economic incentives for clean development. It can help to mobilize the financial investments required to stimulate clean technology and market innovation, fuelling new and low-carbon drivers of economic growth.

For the purpose of this exercise, GHG emission linked to life cycle of diesel and ammunition are monetized based on current and projected carbon prices. We have assumed the current trading price of carbon at US$ 30/tonne. This is expected to reach US$ 250/tonne in the next 25 to 30 years (Credit Suisse, 2022). The price was arrived based on review of literatures including the proposed floor price suggested by the recent recommendation of International Monetary Fund (Schwerhoff et al., 2022).

3.1.5 Assumptions linked to estimation of economic costs for driving and crew gunnery training

The key consideration for estimation of economic costs includes (i) capital costs and apportioning capital usage attributable to training, (ii) fuel consumption (iii) cost of ammunition and (iv) maintenance. The numbers considered and the corresponding assumptions are presented below.

Capital costs (T-90 tank & T-90 driving and crew gunnery simulator)

Cost of T-90 is assumed to be INR 30 crores. The life of a tank is assumed to be 30 years having a salvage value of 30% of the capital cost. The capital cost and the annual capital depreciation allowance linked to training is 20%. The depreciation is distributed over a period of the life of the tank. Further the capital cost of T-90 driving, and crew gunnery simulator is assumed at INR 2.5 crores. The life of a simulator is assumed to be 15 years having a salvage value of 5% of the capital costs.

Fuel costs

The current market price of diesel is assumed at INR. 90/ litre. Based on the growth in price of diesel as observed over the last five years, it has been assumed that diesel price will increase at an average annual rate of 7.5% over a period of 30 years. It is assumed that the cost of electricity for running simulators is extremely low and hence not factored into the calculation. Furthermore, it has least environmental implications as the same can be procured from renewable sources.

Ammunition costs

For ease of the study, it is assumed only one type of ammunition namely, HEAT has been shifted from live firing to simulator. The cost of each 125 mm HEAT ammunition is assumed at US$800. The exchange Rate is assumed at INR 80 per US$. As discussed earlier, 20 HEAT shots are fired for training purposes.

Maintenance costs

We assume that an engine overhaul is scheduled after every 1200 km. Therefore, it is not a fixed annual cost rather incurred over varying intervals, depending on the amount of training. We assumed the maintenance cost at 10% of capital cost. However, the annual logistics costs (including manpower support, to and fro transportation, and cost incurred in arrangement of other training requirements) of a T-90 on-field tank is not considered. Hence to factor in the training apportioned maintenance cost, the capital cost assigned to training is considered and 10% of this cost is used to arrive at the estimate. For driving simulator and crew gunnery simulator an annual maintenance of 10% of the capital cost has been considered.

Discount factor

The discount rate refers to the rate of interest that is applied to future cash flows of an investment to calculate its present value. It is the rate of return that companies or investors expect on their investment. An investment's net present value computed through discounting reveals its viability. Here the discount rate of 7.3% is considered based on the review of literature and inputs from subject matter experts.

3.2 Estimation of Avoided Costs from Use of Driving Simulators

The estimation of avoided costs from the use of simulators is presented under two broad categories (i) environmental costs and (ii) economic costs. The breakdown of the costs for these two categories are presented in Table 8.

Table 8: Present discounted value of total costs (over 30 years) for imparting on field driving training

Cost Heads	PDV Cost (INR)
Carbon Cost (in ₹)	₹1,52,947
Diesel Cost	₹11,63,482
Periodic Maintenance Cost	₹1,32,31,577
Depreciation Cost	₹1,68,61,682
Total	₹3,14,09,690

Source: TERI Analysis

Assuming a total distance of 3000 km to be covered from imparting training the present discounted value of costs per km is INR 10,470/km.

However, if this training is imparted on a simulator the total incurred costs are presented in Table 9. It is important to note here that a simulator life is 15 years, therefore for the assessment of 30 years, capital costs of 2 simulators have been considered.

Table 9: Present discounted value of total costs for imparting driving training on simulator

Cost head	PDV (Costs)
Maintenance Cost	₹3,01,10,147
Depreciation Cost	₹1,90,69,760
Total	₹4,91,79,907

Source: TERI Analysis

It is clearly evident that if 100 km per annum of on field training is moved to simulators, the costs are slightly higher to what will be incurred on the latter if we were to assume that one simulator will serve one on field tank. Since simulators serve multiple on field equipment, the benefits will get correspondingly higher. Moreover, since there are hardly any key cost implications from additional usage of simulators, the cost per km falls significantly if utilization goes beyond 3000 km (over the life of 30 years) on simulator. Also, it is important to mention that certain costs of on field T-90 tank have not been assumed, including costs of logistics, the safety, time and efficiency gains and the environmental cost linked to the use of consumables. So, it can be concluded with a reasonable level of confidence that if these aspects are factored in, it will further increase the cost per km for on field training rendering simulators to be more environmentally friendly and economically viable.

Additionally, a driving simulator could be useful in impart training by avoiding the usage of multiple on field tanks on regiment (45 tanks) and squadron (15 tanks) level, thus it could lead to higher environmental and economic savings due to training shifted to the driving simulator. The environmental and economic cost associated with the 100 km driving training at regiment level and squadron level is presented in Table 10 with the comparable cost of driving simulator for the same level of training.

Table 10: Comparative costs of on field driving training vis-à-vis training on simulator

Cost Heads	PDV costs of operating 45 tanks over a period of 30 years for training	PDV costs of operating 15 (per squadron) tanks over a period of 30 years for training	PDV of costs of a simulator over a period of 30 years
Carbon Cost	₹68,82,615	₹22,94,205	NA
Diesel Cost	₹5,23,56,698	₹1,74,52,233	NA
Periodic Maintenance Cost	₹59,54,21,005	₹19,84,73,668	₹3,01,10,147
Depreciation Cost	₹75,87,75,708	₹25,29,25,236	₹1,90,69,760
Total	₹1,41,34,36,026	₹47,11,45,342	₹4,91,79,907
Cost per annum	₹4,71,14,534	₹1,57,04,845	₹16,39,330
	Benefits of using one simulator for 45 tanks	**Benefits of using one simulator for 15 tanks**	
Over 30 years	₹1,36,42,56,119	₹42,19,65,435	
Annually	₹4,54,75,204	₹1,40,65,515	

Source: TERI Analysis

The usage of simulator at regiment level and squadron level could lead to avoidance of INR 4.54 crores and INR 1.40 crores per annum, respectively. Further, as mentioned in Section 3.1.4, the simulator usage has positive implications on the front of GHG emissions. At the regiment and squadron level, simulator could lead to avoidance of 1919 tonnes and 640 tonnes of CO_2eq, respectively over the life of 30 years.

3.3 Estimation of Avoided Costs from Use of Crew Gunnery Training Simulators

The estimation of costs arising from on field crew gunnery training is presented in Table 11. The environmental costs include the life cycle emissions costs arising from diesel and ammunition manufacturing and usage. The economic costs include maintenance, and depreciation allowance attributable to on-field crew gunnery training.

Table 11: Present discounted value of total costs for imparting on field training that can be moved to simulators (20 shots per tank) over the life of 30 years

Cost Heads	PDV Cost
Fuel Cost	₹4,60,855
Maintenance Cost	₹1,32,31,578
Carbon Cost of Diesel	₹60,580
Cost of Ammunition	₹5,25,08,607
Wear and Tear of Barrels	₹26,25,430
Carbon Cost of Ammunition	₹2,32,325
Depreciation Cost	₹1,68,61,682
Total	₹8,59,81,057

Source: TERI Analysis

Assuming a total firing of (20*30) 600 shots, the on-field present discounted value of costs per shot is estimated at INR 1,43,302.

However, if this training is imparted by a crew gunnery simulator, the present discounted value of incurred costs is significantly reduced as presented in Table 12.

Table 12: Present discounted value of total costs for imparting crew gunnery training on simulator

Cost head	PDV (Costs)
Maintenance Cost	₹3,01,10,147
Depreciation Cost	₹1,90,69,760
Total	₹4,91,79,907

Source: TERI Analysis

Assuming a total firing of (20*30) 600 shots, the present discounted value of costs per shot is estimated at INR 81,967 in a simulator**.** Hence a transition of crew gunnery training to simulators will lead to around half of the current costs that is incurred on on-field training. Further, additional shots can be attempted on simulators with no additional costs thereby further increasing the cost effectiveness of simulators.

Nevertheless, the crew and gunnery simulator could lead to the cost avoidance for multiple tanks at regiment and squadron level. Hence, the simulator benefits are not only restricted up to conserved utilization of on field tanks, further the cost of ammunitions, fuel and maintenance will also be avoided. Table 13 presents the environmental and economic costs associated with 20 rounds of ammunition fire in crew gunnery training at the regiment and squadron levels. It also includes the comparable cost of using a driving simulator for the same level of training.

Table 13: Comparative costs of on field crew gunnery training vis-à-vis training on simulator

Cost Heads	PDV costs of operating 45 tanks over a period of 30 years for training	PDV costs of operating 15 (per squadron) tanks over a period of 30 years for training	PDV of costs of a simulator over a period of 30 years
Fuel Cost	₹2,07,38,488	₹69,12,829	NA
Maintenance Cost	₹59,54,21,005	₹19,84,73,668	₹3,01,10,147
Carbon Cost of Diesel	₹27,26,087	₹9,08,696	NA
Cost of Ammunition	₹2,36,28,87,308	₹78,76,29,103	NA
Wear and Tear of Barrel	₹ 11,81,44,365	₹3,93,81,455	NA
Carbon Cost of Ammunition	₹1,04,54,605	₹34,84,868	NA
Depreciation Cost	₹75,87,75,708	₹25,29,25,236	₹1,90,69,760
Total	₹3,86,91,47,566	₹1,28,97,15,855	₹4,91,79,907
Cost per annum	₹12,89,71,586	₹4,29,90,529	₹16,39,330
	PD Benefits of using one simulator for 45 tanks	**PD Benefits of using one simulator for 15 tanks**	
Over 30 years	₹3,81,99,67,659	₹1,24,05,36,148	
Annually	₹12,73,32,256	₹4,13,51,199	

Source: TERI Analysis

The utilization of crew gunnery simulators at the regiment and squadron levels has the potential to result in cost savings of INR 12.7 crores and INR 4.13 crores per annum, respectively. Additionally, the use of simulators could lead to reduction of GHG emissions. Specifically, at the regiment and squadron level, the implementation of simulators could potentially prevent the emission of 3676 tonnes and 1225 tonnes of CO_2 equivalents (CO_2eq) over a span of 30 years. The major cost and emissions savings comes from the ammunition avoidance.

4. Assessing Benefits and Costs of On-field Light 4W Vehicles vs Driving Simulator

The Indian Army uses various types of light 4-wheel drive vehicles ranging from 250 CWT to 1.5 tonne which include Maruti Gypsy, Maruti Ciaz, Mahindra Jeep, Tata Safari Storme, and more. Although the base model/ chassis and other components of these vehicles are designed by OEMs, the vehicle production and modification used to take place in Armed Forces Ordinance Factory. However, in recent times, many OEMs are developing these products directly for the defence sector and these are delivered without further retrofitting in the ordinance factories.

Drivers of these vehicles of the armed forces need specialised training to be able to drive on and off-road and through varied and rugged terrain. However, considering the high fuel prices and maintenance costs and consequent carbon emissions, defence experts/retired personnel believe that 80% of the training requirements can be fulfilled by using a driving simulator. These have a diverse range of driving, landscapes modes (terrain setting) and environmental conditions installed within them, which provides a real-life experience.

4.1 Assumptions for Estimation of Avoided Cost Arising from Transition of On-field Driving Training to Simulators.

4.1.1 Assumptions related to selected environmental and economic parameters of light 4W vehicles

It is assumed that a total distance a light 4W vehicle can be used for training purpose in a month is 100 km. Thus, in a year, the distance covered will be 1200 km. Assuming that the life of a vehicle will be 15 years, the total distance available for a vehicle is 18000 km.

The cost of a light 4W vehicle is assumed at INR 10,00,000. Considering vehicle utilization for operational activities alongside, it is assumed that capital cost proportioned to training activities comes to 20% of the capital cost. Further, the salvage value of the capital cost is assumed to be 10% of the product value. The annual maintenance cost is 5% of the capital costs while the logistics cost is assumed to 10% of the maintenance. These estimates were arrived based on discussion with subject matter experts and with selected vehicle OEMs. This includes manpower support, to & fro transportation, and cost incurred in arranging of other training requirements.

The average fuel efficiency of a vehicle is assumed to be 6 km/litre. Therefore, the annual consumption of fuel attributable to on field training is 200 litres. Thus, the fuel consumption attributable to training for the entire lifetime of a vehicle is 3000 litres. These vehicles run on petrol, whose price is taken at INR 95/litre for the base year, i.e., the prevailing market price. An annual inflation of 7.5% in the petrol price has been used based on the CAGR over the period 2015 – 2020.

For the driving simulator, the total capital cost is assumed at INR 3,00,000. Salvage value of the driving simulator is 5% of capital cost. The annual maintenance cost of driving simulator system is 10% of capital cost annually. The estimates are arrived at based on discussion with experts representing simulator manufacturers in India.

The assessment of the environmental burden associated with on-field training has been restricted to the combustion of fossil fuel. As mentioned above, the 4-wheeler light vehicle uses petrol as fuel which has environmental burden associated with petrol production as well as tail pipe emissions on petrol combustion. Life cycle impacts of petrol production have harmful environmental consequence in terms of acidification, ozone depletion, eco-toxicity, and human toxicity. Due to lack of data, we have considered only GHG impact of tailpipe emissions.

The environmental impact linked to production and use-phase of 1 litre of petrol is presented in Table 14.

Table 14: Environmental Impacts associated with per litre of petrol production and use-phase

	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC11 eq.	Cases	Cases	PAF
Upstream	0.56	0.00417	1.26E-05	9.36E-07	2.61E-09	2.02E-08	116.97
Tailpipe	2.3	0	0	0	0	0	0
Total	2.9	0.00417	1.26E-05	9.36E-07	2.61E-09	2.02E-08	116.97

Source: TERI analysis

At the tailpipe, petrol combustion is estimated to release 2.3 kg CO_2 eq./litre while other GHG emissions released during petrol production contribute about 0.56 kg CO2. /litre. Hence the total emission per litre of petrol combusted is 2.9 kg CO_2 eq./litre. The fuel economy of an on field light 4W vehicle is 6 km/litre which is equivalent to 0.167 litres/km. Therefore, to cover 1200 km per year and 18000 km during the entire lifetime, the amount of petrol required is 200 litres and 3000 litres respectively. Therefore, the total environmental burden of running an on-field light 4W vehicle is given in Table 15.

Table 15: Environmental burden associated with 204 litres and 3060 litres of petrol production and usage

	Global Warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4^{-3} eq.)	Ozone depletion (kg CFC11 eq.)	Human toxicity, carcinogenic (cases)	Human toxicity, non carcinogenic (cases)	Ecotoxicity (PAF)
Light 4W driving vehicle per year	580	0.83	0.0025	0.0002	0.0000005	0.000004	23394
Light 4W driving vehicle over the lifetime	8700	12.51	0.037	0.003	0.000008	0.00006	350910

Source: TERI analysis

As mentioned in the previous chapter, carbon pricing (or CO_2 pricing) is a method for nations to address climate change. The cost is applied to greenhouse gas emissions in order to encourage polluters to reduce the combustion of coal, oil and gas – the main driver of climate change. The method is widely agreed and considered to be efficient. Carbon pricing seeks to address the economic problem that emissions of CO_2 and other GHGs are a negative externality – a detrimental product that is not priced by any market.

For this exercise, the current trading prices of carbon (at US$ 30/tonne) have been assumed and this is expected to reach US$ 150/tonne in the next 15 years. The price was arrived based on literature review including the proposed floor price suggested by the recent recommendation of International Monetary Fund (IMF, 2022).

4.2 Estimation of Environmental and Economic Costs from Use of Light 4W Vehicle Simulators

The estimation of costs from use of one 4W light vehicle for training is presented under two broad categories (i) environmental costs and (ii) economic costs. The breakdown of the costs for these two categories are presented in Table 16.

Table 16: Present discounted value of total costs (over the 15 years period) for imparting on field training driving that can be moved to simulators

Cost heads	PDV
Fuel Cost	₹2,69,104
Maintenance Cost	₹89,378
Logistics Cost	₹8,938
Carbon Cost	₹31,742
Cost of Capital Usage	₹1,07,254
Total	₹5,06,415

Source: TERI analysis

Assuming a total distance of 18,000 km covered over the lifetime of the vehicle the present discounted value of costs per km is INR 28.2/km.

However, if this training is imparted on a simulator the total incurred costs is presented in Table 17.

Table 17: Present discounted value of total costs (over the 15 years period) for imparting driving training on simulator

Cost head	PDV (Costs)
Maintenance Cost	₹ 2,68,134
Depreciation Cost	₹ 1,69,819
Total	₹ 4,37,953

Source: TERI analysis

It is important to note here that a simulator will be able to impart significantly more training at no additional costs and hence the cost of operations per km will fall significantly with increased usage.

Assuming a regiment has 12 light 4-wheel vehicles that could be used for driving training. If the simulator is used to provide the equivalent training, the environmental and economic costs associated with 100 km per month on 12 vehicles for the period of 15 years and comparable simulator cost is presented in Table 18.

Table 18: Comparative costs of on field light vehicle driving training vis-à-vis training on simulator

Cost Heads	PDV costs of operating 12 light 4-wheel vehicles in a regiment for training over a period of 15 years	PDV of costs of a simulator over a period of 15 years
Carbon Cost	₹3,80,898	
Petrol Cost	₹32,29,249	
	₹1,07,253	
Maintenance Cost	₹10,72,537	₹2,68,134
Depreciation Cost	₹12,87,045	₹1,69,819
Total	₹60,76,985	₹4,37,953
Cost per annum	₹4,05,132	₹29,196
	Benefits of using one simulator for 12 vehicles	
Over 15 years	₹56,39,032	
Annually	₹3,75,936	

Source: TERI analysis

Thus, one driving simulator could provide annual savings of INR 3.75 lakhs at a regiment level and around 103 tonnes of CO2 eq. avoidance over the life of 15 years. Furthermore, increasing the use of automated driving simulators provides an additional opportunity to enhance confidence and improve preparedness among trainees. Simulators also offer the advantage of conducting “After Action Reviews,” where the entire training process is recorded, starting from task assignment to its completion. By reviewing these recordings, trainee drivers can identify and analyse their mistakes, facilitating a better understanding of the learning process and allowing for the elimination of errors in subsequent stages of training.

5. Live Ranges versus Advance Weapons Simulator (AWeSim) and Containerized Tubular Shooting Ranges for Firearms

Basic weapons training is given to all armed forces personnel, and it includes small calibre arms training. In addition, armed forces personnel are also trained to use advanced weapons – small and medium calibre arms, sniper rifle, etc. This training is outdoor, on ground and land-to-land.

The use of such ammunition in live ranges can have various environmental impacts depending on the specific type of ammunition and the circumstances in which it is used. Shooting ranges cause consistent site-specific degradation and contamination. The most common and extensive live-fire training occurs on small arms ranges, which are associated with extensive heavy metal contamination, with lead being the most notable contaminant. The weathering and oxidation of lead bullets leads to the contamination of soils, groundwater, and surface water sources. It has been noted that high lead concentration in soils can reduce vegetation growth and species richness.

Firing ranges have a very large land requirement. As consequence of continuous training over several years, the land and the associated landscapes can suffer from degraded soil structure and quality. This altering of the landscape results in the habitat loss of the fauna and flora of the region. Also, the nearby land gets contaminated due to repeated use of the ammunition and there is significant dust generation due to mass movements which may degrade the air quality of the surrounding areas in the long term.

5.1 Assumptions for Estimation of Avoided Cost Arising from Transition of On-field Arms Training to Simulators.

A soldier of an infantry battalion is allotted 200 fires of small arms in a year. Out of the total allocation, 50% of that can be transitioned to the virtual simulation. In an infantry battalion there are approx. 800 soldiers, who need to be trained in small arms firing. Therefore, the total number of fires in a year that could be shifted from live ranges to simulator for small arms training is assumed to be 80,000 (100*800). Among several categories of small arms training in live ranges, for the ease of calculation we have considered the 80:20 ratio of arms firing between 5.56 mm rifle and 7.62 mm Light Machine Gun (LMG) shooting. The major environmental and economic cost implication in arms firing training arises due to ammunition.

The manufacturing and point of fire (POF) impact of per 5.56 mm and 7.62 mm ammunition is given in Tables 19 and 20.

Table 19: Manufacturing and POF burden of a 5.56 mm ammunition for rifle

Impact category	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC11 eq.	Cases	Cases	PAF
Manufacturing	6.46E-01	1.46E-02	1.39E-03	8.00E-07	2.62E-08	1.95E-06	1.64E+03
POF	7.03E-07	6.93E-09	0.00E+00	0.00E+00	4.21E-13	1.50E-10	6.02E-03
Total	6.46E-01	1.46E-02	1.39E-03	8.00E-07	2.62E-08	1.95E-06	1.64E+03

Source: TERI analysis

Table 20: Manufacturing and POF burden of a 7.62 mm ammunition for LMG

Impact category	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC11 eq.	Cases	Cases	PAF
Manufacturing	8.61E-01	1.95E-02	1.85E-03	1.07E-06	3.49E-08	2.60E-06	2.19E+03
POF	7.03E-07	6.93E-09	0.00E+00	0.00E+00	4.21E-13	1.50E-10	6.02E-03
Total	8.61E-01	1.95E-02	1.85E-03	1.07E-06	3.49E-08	2.60E-06	2.19E+03

Source: TERI analysis

Total number of shots that are to be trained on the simulator are 80,000 as mentioned earlier. We assume that these 80,000 shots are divided among the two armament categories i.e., the 5.56 mm rifle and 7.62 mm light machine gun in an 80:20 proportion. Therefore, a total of 64,000 shots are fired from 5.56 mm rifle and 16,000 from 7.62 mm LMG, respectively. The total environmental burden from firing 64,000 shots of 5.56 mm rifle and 16,000 shots of 7.62 mm LMG is given in Table 21.

Table 21: Total environmental burden of small arms firing in live range

Impact category	Global Warming	Acidification	Eutrophication	Ozone depletion	Human toxicity, carcinogenic	Human toxicity, non-carcinogenic	Ecotoxicity
Unit	kg CO_2 eq	kg SO_2 eq	kg PO_4^{-3}	kg CFC_{11} eq	Cases	Cases	PAF
6400 rounds of 5.56 mm	41344	934	89	0.05	0.002	0.12	104960000
1600 rounds of 7.62 mm	13776	312	29.6	0.02	0.006	0.04	35040000
Total	55120	1246	119	0.07	0.008	0.06	140000000

Source: TERI analysis

Therefore, a total of 55120 kg CO2 eq. can be avoided through application of simulator for small firearms.

5.2 Choice of Simulators for Small Arms Training

Among several simulator technologies, Advanced Weapon Simulators (AWeSim) and Simulated Containerized Shooting Ranges are used for small arms fire training.

Advanced Weapons Simulator (AWeSim)

Advance weapons simulator (AWeSim) is a video-based firearms training simulator, designed to provide comprehensive training from basic training to honing firing skills, improving weapon handling and testing the capability level of trainees in complex and war-like scenarios. With smart authoring system, multi-scenario in-built system, and in-service weapons recoil-features, it helps in imparting marksmanship, judgemental and effective reflex training in a sustainable manner. It provides grouping, static, and moving targets practice with detailed performance reports which helps in better evaluation of skill levels.

Containerized Tubular Shooting Ranges (CTSR)

The environmental impacts associated with the arms firing, and safety issue while creating complex war-like situations, could be avoided with the installation of Simulated Live Ranges. This is a self-contained, transportable, small-arms live-fire shooting facility. It offers an environment friendly training facility including target retrieval, effective judgemental reflex training and ensure arms marksmanship. Live Range Simulator is a modern equipment with installed soft 'bullet catchers', air filters, and length extension system. The system enables the avoidance of the release of harmful gases to the environment and captures the bullet shells for recycling.

The intent of using these simulators is not only up to train and improve shooting accuracy but also to improve weapon handling skills and test the level of capability under internal conflict and war-like realistic situations. These training activities are overseen by the supervisor, to ensure the safety of weapons and personnel, along with following the government regulations. The shooting range could be indoor or outdoor, depending on the target range. Long-distance shooting training exceeding 1200 yards (1100m) takes place outdoors. It is necessary to build a high retaining safety wall beyond the target line to catch and prevent misaligned shots, errand projectile ricochets, and shots beyond the bounds.

5.3 Estimation of Environmental and Economic Costs from Use of AWeSim

The estimation of costs from use of live ranges vis-à-vis AWeSim for small arms training is presented under two broad categories (i) environmental costs and (ii) economic costs. We take the life of an AWeSim to be 10 years. The assessment and comparison have been done over this period. The breakdown of the costs for these two categories are presented in Table 22.

Table 22: Present discounted value of total costs (over the 10 years period) for imparting on field arms training that can be moved to simulator

Cost Heads	PDV
Carbon Cost	₹18,20,880
Ammunition Cost	₹3,25,00,550
Barrel Maintenance	₹3,25,005
Total	₹3,46,46,435
Cost Per Annum	₹34,64,643

Source: TERI analysis

Assuming the total number of shots in a year 800,000 shots over the lifetime of 10 years, the present discounted value of each shot is INR 43.

However, if this training is imparted on the AWeSim, the total incurred costs are presented in Table 23.

Table 23: Present discounted value of total costs for imparting arms training on simulator

Cost Head	PDV (Costs)
Maintenance Cost	₹41,56,325
Depreciation Cost	₹58,88,126
Total	₹1,00,44,451
Cost per annum	₹10,04,445

Source: TERI analysis

The application of AWeSim for small arms firing training has the potential to generate significant cost savings. Specifically, it can lead to annual savings of INR 24.60 lakhs annually. Additionally, the use of simulators contributes to reducing GHG emissions due to avoidance of ammunition which comes to around 55 tonnes in the period of 10 years.

6. Anti-Aircraft Air Defence Simulator

The Igla (9K38 Igla-s and its subsequent versions), is a Russian/Soviet man-portable infrared homing surface-to-air missile (SAM) system or man-portable air-defence systems (MANPADS or MPADS) used by Indian army. The IGLA is a MANPADS, which means it is a shoulder-fired missile system. It can be operated by a single soldier on the ground. They are guided weapons designed for use against visible aerial targets at short range that can engage aircraft, helicopters and unmanned aerial vehicles (UAVs) cruise missile, using high explosive blast fragmentation. The system consists of a missile inside a disposable tube, a grip stock and a battery to charge the missile.

In April 2022, the Indian Army inducted several 9K38 Igla-s systems. A typical 9K38 Igla-s consists of dual waveband guidance system, utilizes an infrared homing guidance system to track and engage targets. It is equipped with a seeker that detects and locks onto the heat signature emitted by the target's engines or exhaust. Igla-S is equipped with a solid fuel rocket motor engine with an operational range of 6.0 Km and maximum speed of 570m/s with flight ceiling length of 3.5 km. It has a warhead of 1.17 kg with 390 g high explosive fitted with a contact and grazing fuse. The current one-unit cost of system is $60,000 (~50 lakhs) (Deb, 2020). It is an improved variant of the Igla MANPADS with greater combat effectiveness, particularly for cruise missile firing and target identification.

As per discussion with the field experts, it was indicated that training on this air defence system is quite critical. Due to high ammunition cost, lack of ease of putting up a target (in air) and high maintenance cost, Igla is only an operational equipment. Whatsoever training is being imparted is only through the dummy model which does not impart realistic operational skills and provide performance evaluation. Thus, a deficiency in training arises due to restrictions imposed on Igla. This can have adverse consequences in various combat situations.

It is important to note that any weapon system, including missiles, has the potential to cause environmental damage. Especially Igla-S as its warhead has increasingly high explosive charge and fragment count. The environmental impact of Igla missiles is primarily associated with their propulsion system and the potential for collateral damage during use. Direct impact includes environmental damage due to the explosion and fragmentation. When Igla missiles are launched, they utilize solid rocket propellants that burn quickly and release exhaust gases, hazardous materials especially the chemical and heavy metal into the atmosphere. These gases can contribute to air pollution, contaminate soil and water bodies, although the overall impact is generally localized and short-lived.

This impact also results in the destruction of structures, vegetation, and wildlife in the immediate vicinity. Igla launches produce a significant amount of noise, which can disturb wildlife and human populations nearby. Additionally, elevated noise levels due to equipment operation have the potential to affect the behaviour and hearing sensitivity in birds, sea turtles, and fish. Loud sounds might cause these organisms to quickly react, altering their normal behaviour either briefly or more long term or may even cause physical injury. The extent of these effects depends on the frequency, intensity, and duration of the sound pressures as well as on the hearing ability and physiology of the organism. Further, combustion of propellant during rocket launch generates a lot of toxic gaseous pollutants to the local atmosphere. Concentration of gases such as SO_2, NO_X, CO, HCN and Cl amalgamate within the atmosphere (JK et al., 2014). The fragments which arise during propulsion contaminate the water resources and leach into the soil contaminating ground water. Even if the training on the Igla missiles is prohibited, it can be considered that the use of these high-powered weapons will require special training areas to safely contain the blast radius and noise from civilian areas. This also leads to the land allocation constrains and along with land use changes. Even sometimes displacement of nearby habitation due to security and safety reasons adds up to the additional cost of rehabilitation and resettlement.

Considering the economic and the environmental constrains, Igla missiles possess in front of a regiment's training requirement, the usage of its simulator counterpart becomes more crucial in imparting the essential operational skillset. It's worth noting that the specific environmental impact of Igla missiles may vary depending on the circumstances of their deployment, including the location, the nature of the conflict, and the targeting strategies employed. But there is no counter-argument to the possible environmental implication of the Igla missiles as discussed above. Simulators address the training gap due to banned use of the Igla while also mitigating the release of toxic gases within the atmosphere.

According to field experts interviewed, the armed forces can immediately impart actual training using simulators leading to better preparedness on anti-aircraft air defence system.

The simulator counterparts available are designed for training of Igla gunners in combat operating skills and they provide target practice leading to improved skills to face realistic conditions as well as psycho-physiological experience at the time of launch. Anti-Aircraft Air Defence Simulators (3ADS) are user-friendly and provide data of missile launch, details of target movements and hit-miss information for after action reviews and performance evaluation.

7. Inferences and Conclusion

Climate change has become a critical issue in security policy and military organizations are increasingly involved in addressing it. While they understand the criticality of its impact on security and military operations, more information is currently needed about how armed forces, which often possess substantial resources and have the capacity to exercise force, actually account for climate change and its relationship to security. Collectively, the new possibilities offered by simulation-based training can help militaries provide high quality and regular planned training to their armed forces while simultaneously addressing fiscal, environmental, and safety concerns.

In this report, we have tried to critically assess how the infusion of technological interventions, especially simulators, can help the armed forces to not only improve the efficiency quotient of their training capacity, but also reduce their overall GHG emission to the environment. The annual cost benefits (savings) and GHG emissions that can be saved on switching to different simulator technologies for military training exercises is presented in Table 24.

Table 24: Annual economic and GHG emissions savings by switching to simulator technologies

Type of Simulators	Annual Savings at Regiment Level (in ₹)	Annual Savings at Regiment Level (GHG in tonnes of CO_2eq.)	Annual Savings at Squadron Level (in ₹)	Annual Savings at Squadron Level (GHG in tonnes of CO_2eq.)
T-90 DS	₹4.54 crore	64 tonnes	₹1.40 crore	21 tonnes
T-90 CGS	₹12.7 crore	122.5 tonnes	₹4.13 crore	41 tonnes
Automated Driving Simulator	₹3.75 Lakhs	6.87 tonnes	NA	NA
Benefits to an Infantry Battalion in case of 50% transition from Live ranges firing to simulator				
AWeSim	₹24.60 Lakhs per annum		5.5 tonnes CO_2eq.	

Source: TERI analysis

The sustainability benefits of selected simulator technologies present a promising picture in terms of overall GHG emission reduction as well as in economic terms. These reduced GHG emissions reflects the reduced consumption of fossil fuels like petrol and diesel, as well as material extraction and processing for manufacturing ammunition used in trainings. T90 CGS shows the highest saving due to avoided use of heat ammunition, and diesel.

There is a growing realization within the Indian armed forces leadership that climate change is emerging as a security threat, and that there is a need to develop a long-term strategy to deal with the eventualities that may arise due to its catastrophic impact. While the effects of climate change have proven to significantly impact military operations and lower the operational effectiveness of the defence forces, so far, our climate change response have almost entirely been non-military in nature. Additionally, more policy action is needed towards incorporating the responses of heightened threats brought on by climate change into the current military policy. Countries such as the USA, France and the United Kingdom serve as a good example of how the incorporation of climate change principles within military planning and operations can be successfully implemented.

For the principles of climate change to become a guiding feature in military operations, we must first conduct a thorough analysis of the impact of climate change on the various spheres of military activities. An integrated approach in the armed forces involving steps such as switching to simulators wherever possible, achieving the ultimate goal of an 80-20 ratio of simulator-on field training. The simulators training in Army has proven its value in reducing fossil fuels-based energy consumption, moving to cleaner sources of energy, and reducing overall emissions. By developing the carbon offset mechanism (carbon sinks), the sector could also avail carbon credits in future, which would further help in mitigation of climate change and will complement efforts being made by the government. India's national security strategy must prioritize the incorporation of principles of climate change as part of its plan of action, given the increasing occurrence of extreme climate events and their impact on the environment. The infusion of simulator-based training within the armed forces checkmarks all aspects of sustainability. From emission dissipation and fiscal cost reduction to improvement in training efficiency, simulators are a packaged technological apparatus that can contribute in India's quest of achieving its net zero target by 2070.

While the study projects a cohesive picture of how simulators can help the Army reduce its carbon footprints, there is an imminent need to further understand their emission impacts across other branches of defence, such as Air Force and Navy where the simulators usage is considerably higher. A comprehensive analysis of its utilization in the services can further help us to get an exhaustive understanding of the forces ability to reduce carbon emissions. This degree of macro analysis can help the defence sector collectively strategize its operations and further help India achieve its national and international climate commitments.

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List of Annexures

Annexure 1: The environmental burden associated with 1 kg of energetic and non-energetic material

Impact Category	Steel	Copper	Aluminium	Brass	Lead	Electronic parts	Black powder	HMX	PETN	RDX	TNT
Global Warming (kg CO_2 eq.)	2.17E+00	8.54E+00	1.88E+01	7.64E+00	2.51E+00	6.21E+01	12.9	42.4	5.37	8.59	5.06
Acidification (kg SO_2 eq.)	0.005883398	0.32636535	0.082117676	0.24346701	0.020216052	0.48967339	0.0345	0.135	0.0239	0.0245	0.0619
Eutrophication (kg $PO4_{-3}$ eq.)	7.40E-05	0.031893907	0.000700405	0.023063763	0.000631467	0.10819254	0.00906	0.00538	0.00314	0.0103	0.00546
Ozone depletion (kg CFC11 eq)	3.87E-07	1.68E-05	4.62E-06	1.28E-05	1.34E-06	4.43E-05	5.15E-07	3.92E-06	1.34E-07	5.34E-07	1.88E-07
Photochemical Oxidation (kg C_2H_4 eq)	0.004326948	0.12265819	0.044756121	0.092001674	0.013855833	0.51541551	0.00229	0.00258	0.00104	0.000773	0.00209
Human toxicity, carcinogenic (cases)	9.26E-08	3.91E-07	8.74E-07	3.02E-07	1.45E-07	1.14E-06	3.31E-10	2.17E-09	1.12E-08	9.37E-10	1.23E-10
Human toxicity, non carcinogenic (cases)	2.39E-07	3.30E-05	3.02E-06	3.07E-05	5.50E-06	4.00E-05	1.31E-09	6.41E-09	8.47E-10	8.25E-10	5.9E-10
Ecotoxicity (PAF)	492.8484	34018.665	5013.8939	26307.488	2704.3118	71752.56	0.00322	0.0662	0.226	0.0506	0.00178

Annexure 2: The composition of a generic large and small calibre ammunition

The composition of a generic large ammunition

Ammunition components		Amount (kg)
Warhead	**Steel casing**	**25.08452073**
	Copper (driving band)	0.353303109
	Composition B	6.00615285
	PETN (booster)	0.014132124
Propellant charge	Triple base powder	6.712759067
	Black powder	0.038863342
	Boron potassium nitrate (igniter)	0.021198187
	Lead (decoppering agent)	0.060061528
Fuze	Aluminium	0.317972798
	Brass	0.317972798
	Electronic parts	0.070660622
	RDX (detonator)	0.001413212
Container	Steel	15.54533679
Projectile		25.08452073
		0.353303109

The composition of a generic small ammunition

Substance	mg/bullet
Carbon dioxide	198.65
Carbon monoxide	101.79
Nitrogen monoxide	3.8
Nitrogen dioxide	0.64
Ammonia	3.1
Hydrogen cyanide	1.77
Methane	1.1
Lead	3.14
Copper	0.55
Zinc	0.12
Antimony	0.37

Annexure 3: The Point of Fire (POF) and detonation emissions of a generic large and small calibre ammunition is given below:

The Point of Fire (POF) emissions of a generic large calibre ammunition

Carbon dioxide	2.74	Hydrogen cyanide	0.00378
Carbon monoxide	4.64	Acrylonitrile	0.0000229
Nitrogen monoxide	0.00039	Acetic acid	0.000144
Nitrogen dioxide	0.000314	Ethyl Acetate	0.0000898
Formaldehyde	0.0000863	Furan	0.0000898
Acetonitrile	0.00028	Black carbon	0.00155
Acetaldehyde	0.000032	Sulphate	0.000304
Benzene	0.000903	Nitrate	0.000122
Ethylbenzene	0.000219	Ammonium	0.0000969
Toluene	0.000279	PAH	0.00000285
Styrene	0.0000487	Lead (particulate)	0.000000430

Detonation emissions of generic large calibre ammunition

Carbon dioxide	0.191	Nitrogylcerin	0.00000545	1-Propyne	0.00000154
Carbon monoxide	0.00454	Phenol	0.000000409	Valeraldehyde	0.00000817
Oxides of nitrogen	0.00132	Phosphorus	0.0000386	Antimony	0.000015
Sulphur dioxide	0.000354	Propinaldehyde	0.000015	Arsenic	0.000000345
Acetaldehyde	0.0000304	Propylene	0.0000195	Barium	0.0000132
Acetonitrile	0.00000268	Toluene	0.000014	Cadmium	0.000232
Acetophenone	0.00000109	Xylene	0.000000908	Magnesium	0.114
Ammonia	0.0000354	Acetylene	0.00295	Manganese	0.0000636
Benzene	0.0000354	Benzaldehyde	0.00000817	Lead	0.00000331
Beryllium	0.0000000953	2-butenal	0.00000241	Chromium	0.00000772
Carbon disulphide	0.00000368	1-butene	0.00000381	Cobalt	0.00000286
Chloromethane	0.00000218	Cis-2-butene	0.00000109	Copper	0.00000636
Ethylbenzene	0.00000245	Trans-2-butene	0.00000123	Zinc	0.000118
Ethene	0.000099	Diethylphthalate	0.000000953	Dioxin	0.00000000000681
Formaldehyde	0.0000145	Dodecane	0.00000195	Furan	0.00000726
Methyl chloride	0.00000168	Ethane	0.0000318	PM 2.5	0.0726
2-methylnapthalene	0.000000309	Hexaldehyde	0.0000059	PM 10	0.163
Naphthalene	0.00000272	Methyl ethyl ketone	0.00000499		

The Point of Fire (POF) emissions of a small calibre ammunition

Substance	mg/bullet
Carbon dioxide	198.65
Carbon monoxide	101.79
Nitrogen monoxide	3.8
Nitrogen dioxide	0.64
Ammonia	3.1
Hydrogen cyanide	1.77
Methane	1.1
Lead	3.14
Copper	0.55
Zinc	0.12
Antimony	0.37