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Original Paper

Preparation for the greenhouse gas emission issues in the national defense

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Abstract: This study reviewed the current readiness levels and future strategies for greenhouse gas emission issues in the military sector of the Republic of Korea (ROK). First, it considered greenhouse gas management policies of foreign and ROK military sectors and analyzed the completeness of the greenhouse gas inventory calculations of the USA, UK, and EU. Although it was not possible to quantitatively analyze the levels of the considered military sector policies and the degree of participation currently underway, it was clear that the military's role in responding to future climate change crises is expanding globally. After that, the study reviewed the research on calculating the greenhouse gas inventory of the ROK military sector and newly calculated the greenhouse gas inventory using its own methodology, including ammunition use and absorption sources creatively. As a result, it was confirmed that approximately 3.45 Mt CO_2-eq (0.5% of the total national emissions) greenhouse gases were emitted by the military sector in 2020. Moreover, the net greenhouse gas emissions were calculated to be high in the order of the air force, army (including units under the direct control of the Ministry of Defense), navy, and marine corps. Most of the emission sources were the uses of aircraft and electricity. From the inventory calculation results, to reduce the greenhouse gas emissions of the ROK military sector, it was concluded that it is necessary to change the fuel use, improve the efficiency of military facilities, and improve the utilization rate of new renewable energy.

Keywords: Greenhouse gas, Military sector, Inventory, Alternative energy, Adaptation strategy

Abbreviations

EEA	European environment agency
EF	Emission factor
EPA	Environmental protection agency
GHG	Greenhouse gas
GIR	Greenhouse gas inventory and research center
GWP	Global warming potential
IPCC	Intergovernmental panel on climate change
MGO	Marine gas oil
MOD	Ministry of defense
ROKN	Republic of Korea navy

1. Introduction

The term "threat" has two military-based meanings: military and non-military threats. The term "supranational" has been added to explain threats that occur in two or more nations. The current climate change crisis falls into the category of "super-national non-military threat." Because the industrialization of human civilization has led to the mechanization of military and mass production, the responsibility and role of the military cannot be overlooked in the climate change crisis, which is a result of industrialization. In accordance with this change, nations that manage "advanced militaries" are gradually demanding the militaries change their perceptions and behaviors to respond to climate change. The management of greenhouse gases (GHGs) is the key to driving this positive change. Thus, GHG management has already become essential in all areas of society, including the military sector. The Republic of Korea (ROK) government has also established various visions, promotion strategies, and development strategies for GHG management: "Green New Deal," "2050 Carbon Neutral," "Carbon Neutral Declaration," and "Public Speech to Present the 2050 Carbon Neutral Vision." **[1]** As an energy-consuming group, it is a matter of time when the military sector will be included in the future national GHG management area, considering such trends in dealing with climate

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Table 1: Policies of foreign militaries and organizations for GHGs and climate change **[2]**

Nations	Policies	Inventory for national defense	Qualitative evaluation
USA	• Assessment of the impact of climate change on security strategies, military operations and infrastructures • Climate change impact assessment of 79 military camps in the United States (2019) • Include climate change matters in key military sector documents (guidelines, strategies, etc.) • Promote carbon emission reduction and eco- friendly technology development • Order to establish of a climate change working group in the military sector (March 2021)	Detail (EPA)	Very Active
China	• Promotion of supporting policies to achieve the national carbon-neutral target of 2060	Unable to confirm	Passive
Japan	• Formulation and promotion of plans for GHG emissions control by the MOD (Substitute 40% or more for next-generation vehicles, reduce vehicle fuel usage by 15%, reduce power consumption, etc.)		Normal
Canada	• 'Defense Energy and Environment Strategy 2020-2023' declaration (16 goals on the themes of energy efficiency, climate change adaptation, sustainability and eco-friendly logistics)		Active
France	• 'Military Energy Strategy' declaration (10 proposals to reduce dependence on oil, introduce new technologies, energy transformation and optimization, etc.)	Not enough (EEA)	Very Active
Germany	• MOD, 'Carbon Neutral Roadmap', 2030 target carbon emissions reduction by 40%		Active
Sweden	• 5 environmental goals based on the 2045 carbon neutral national goal (Reduced electricity and heating energy, expanded waste recycling, environmental protection during training, sustainable consumption, prevention of soil and water pollution)		Very Active
Denmark	• MOD, 'Environment / Energy Strategy 2016-2020' (Environment and Energy Policy, Management, and Climate Accounts)		Very Active
UK	• Military Climate Change & Sustainability Strategic Approach (Adaptation & resilience, Sustainability & net-zero, Global leadership)	Detail (GHG protocol)	Very Active
NATO	• 'NATO 2030 reform plan' declaration to develop carbon emission reduction standards for the military sector (includes climate change countermeasures such as annual evaluation on impact of climate change on troops and missions) (February 2021) • A subject for military sector GHG reduction efforts at NATO summit (June 2021)	Unable to confirm	Very Active
IMO[3]	• The absolute level of GHG emission reduction (at least 50% reduction by 2050) • A wide list of candidate short-term, mid-term and long term measures, including for example further improvement of the EEDI (Energy Efficiency Design Index) and the SEEMP (Ship Energy Efficiency Management Plan), National Action plans, enhanced technical cooperation, port activities, research and development, support to the effective uptake of alternative low-carbon and zero-carbon fuels, innovative emission reduction mechanism, etc. • EEDI phase 2: up to 20% reduction in carbon intensity of the ship (by 2020), EEDI phase 3: up to 30% reduction (by 2025) and long-term measures to reduce carbon intensity of the fleet by at least 70%		

change not only domestically but also abroad.

This study considers the current state of the military in response to the climate change crisis, which is a "supranational non-military threat." Subsequently, the results of the inventory calculations on checking the current level of GHG emissions of the military sector are analyzed. In addition, specific sectors that can reduce direct and indirect emissions of GHGs as well as alternative fuel use closely related to them are considered. From the data used in this research, security-violation or detailed activity data that can be used to infer military information are not disclosed.

2. Policies for GHG reduction and management

2.1 Foreign military

Table 1 lists the GHG reduction policies in foreign military sectors. Although there are differences in the details and scopes of the military sector policies of countries and coalitions on GHGs and climate change, a common perception of their importance can be confirmed. However, looking at the details of the policies of each country, the reduction plans of GHG emissions of facilities and non-tactical vehicles are mainly mentioned, whereas those for equipment including weapon systems like air crafts, vessels, and ground vehicles are not specific. It is evaluated that in-depth studies are blocked by military specificity.

Typically, technical devices for reducing GHGs affect the main and subsidiary performance, including equipment reliability. In addition, the fact that this will increase the initial purchase cost is considered to be the background of the restrictions in the application of GHG reduction technology to military equipment. The maturity of GHG reduction technology should also be considered.

Therefore, adapting GHG reduction technologies as the required operational capabilities and technical requirements in the defense industry as well as institutionalizing GHG emission monitoring and inventorying are the end states of GHG reduction efforts for the military sector.

2.2 ROK national defense

The “Defense Green Growth Promotion Committee” was newly established to participate in the “Low-Carbon Green Growth Promotion Strategy” of the ROK government. Moreover, a series of initiatives including the “Defense Green Growth Promotion Plan” were established and are moving forward ('09-). The main goals of the promotion plan are to improve the efficiency of defense resources, drive the growth of green defense technology, and make all military personnel green citizens. Moreover, along with the following three major strategies, ten major policy issues such as the construction of a green operation training system, development of green defense technology, and creation of a green defense environment have been carried out in parallel **[4]**.

① Climate change response and defense energy innovation

② Creation of new growth engines for national defense

③ Change the lifestyle of military personnel and strengthen the status of green military

Most recently, since 2021, the Ministry of Defense’s (MOD's) Green New Deal (energy efficiency improvement and expansion of green mobility) and the following carbon neutrality promotion issues have been promoted **[5]**:

① Energy efficiency improvement of military facilities, intelligent power grid construction, green remodeling, etc.

② Expansion of the supply of eco-friendly and new renewable energy

③ Expansion of eco-friendly vehicles in the military, compulsory purchase, hydrogen car test operation, etc.

④ Expansion of green mobility infrastructure (hydrogen, electric charging stations, etc.)

However, the fact that there is no mention of establishing an inventory system that identifies GHG emission and absorption sources, monitors GHGs accordingly, and calculates emissions is the limitation of the green policies of the ROK military sector. Using a military sector inventory system that includes GHG emissions of army, navy, and air force equipment, effective act, evaluation, and feedback of the tasks mentioned above can be achieved.

Efforts to calculate the GHG emissions of the military sector, including military equipment, can be found in the United States (US).

3. GHG inventory of national defense

3.1 Foreign military

USA **[6]-[8]**: The GHG emission calculation methodology applied by the US military is based on the Environmental Protection Agency (EPA). The US military has set a classification list based on the use of explosives and ammunition in addition to the GHGs emitted from ground, aviation, and naval military equipment and facilities, and applies emission factors for these. Based on this, the US MOD's GHG emissions research showed that the US military emitted 1,267 MT CO_2-eq between 2001 and 2018. The emissions in 2018 (56 MT CO_2-eq) were higher than the total GHG emissions of Sweden (50.8 MT CO_2-eq) and Denmark (33.5 MT CO_2-eq). The US military's GHG emissions have been gradually declining since the Iraq War (2003–2011).

UK **[9]**: The United Kingdom (UK) publishes official GHG emissions-related military reports each year, but only on buildings. GHG emissions of equipment such as aviation and vessels are disclosed every two years, limiting the confirmation of accurate GHG emission results and methodologies. However, there are cases in which GHG emissions of the military sector have been calculated by private organizations based on the GHG protocol presented by the World Resources Institute and World Business Council Sustainable Development. In these cases, the GHG emissions were calculated by subdividing buildings, aircraft, vessels, and ground equipment. GHG emissions of military industry companies were also presented. The annual GHG emissions of the UK military confirmed in the research results were approximately 3.03 MT CO_2-eq.

EU **[10][11]**: The European Environment Agency (EEA) classifies the military sector's emissions list into two categories: 1.A.5.a. Other, stationary (including military) and 1.A.5.b. Other, mobile (including military, land-based, and recreational boats)

In addition, there is a limitation in that only emission factors for carbon dioxide, methane, and nitrous oxide are presented at the Tier 1 level. Moreover, methodologically, the use of emission factors in the industrial sector is allowed when calculating the inventory of the military sector. Compared with the methodology specified by the EPA, there is a limitation in the specification for application to the military sector. The total GHG emissions of the military sectors of the 27 European Union (EU) member countries in 2018 calculated based on the methodology presented by the EEA are 4.52 Mt CO_2-eq.

It is estimated that emissions from strategic and classified weapons were excluded at the time of calculating GHG emissions of the military sector in the above-mentioned examples. This is expected to be common to all countries because of the management and operational characteristics (confidentiality) of military equipment (weapons and military support systems). In addition, it is judged that the clear grounds, procedures, and reliability of the officially disclosed emission calculation results are undisclosed because of the exclusive character and security reasons of the military. In other words, it is hard to expect transparency and completeness of the inventory calculation principles (transparency, accuracy, completeness, and consistency) in the GHG emission inventory calculation of the military sector. However, such a move to determine GHG inventories internally by countries and their militaries is quite encouraging in the scenario of climate change crisis. In addition, the data accumulated in the inventory calculation process is considered significant in that it will be a basic library for promoting the military's GHG emission reduction and response strategies in the future.

3.2 Inventory study cases for ROK national defense sector

GHG emissions of the ROK military sector can be excluded from the scope of application according to the “Guidelines for GHG and energy target management and operation in the public sector;” therefore, there is no obligation to calculate the inventory. Moreover, the “Guidelines for emissions reporting and certification of GHG emissions trading system” include fuel consumption in the military sector in the “unclassified (stationary and mobile)” sector.

The specific activity data released are about the electric power and fuel consumption of buildings and vehicles of the MOD, Seoul National Cemetery, Defense Computing Information Agency, Defense Media Agency, etc. These are affiliated organizations, and these activity data are very limited and inaccurate in the scope of coverage. Therefore, the calculation of GHG emissions by a bottom-up method by collecting specific activity data, including equipment and field forces, is extremely limited.

Nevertheless, the ROK military has also made efforts to calculate GHG inventories of the military sector by a bottom-up approach. The ROK army's carbon management information system developed in 2009 corresponded to attempting a bottom-up approach for inputting emission and activity data of each equipment and unit into the system on a monthly basis **[12]**. Based on the information accumulated in the army carbon management information system, H. -J. Choi *et al.* calculated the army's carbon emissions in 2018. As a result, it was confirmed that carbon emissions from the use of fuel for stationary and mobile combustion and indirect emissions from the use of electric power accounted for 80% of the carbon emission sources **[13]**. However, the operator of the system had to manually input the data, and it took an excessive amount of time and effort to manage the input data; thus, the army carbon management information system has been off since 2020.

K. -P. Song *et al.* (2017) calculated GHG emissions of the military sector at Tier I and II levels using a top-down approach and the emission factors and methodologies of the Generalized Impulse Response (GIR), Intergovernmental Panel on Climate Change (IPCC), and EPA **[14]**. In the research results, the GHG emissions (Tier I) of the ROK military sector are presented as shown in **Figure 1**. The inventory can be subdivided by fuel type according to Tier II, and **Figure 2** shows the results. In addition, the ratio of GHG emissions depending on the purpose of fuel use for each military force is shown in **Figure 3**.

Based on the calculation results, it is confirmed that the characteristics of the inventory are distinguished between the forces centered on weapon systems (air force and navy) and manpower (army). It can also be seen that GHG emissions are high in the order of aircraft, ground equipment, and vessels, and the emissions due to the operation of these equipment accounts for 80% of the GHG emissions of the military sector. These results underscore the need to develop alternative energy sources and utilize renewable energy to reduce the GHG emissions of the military sector. This discussion is explained in Section 4.

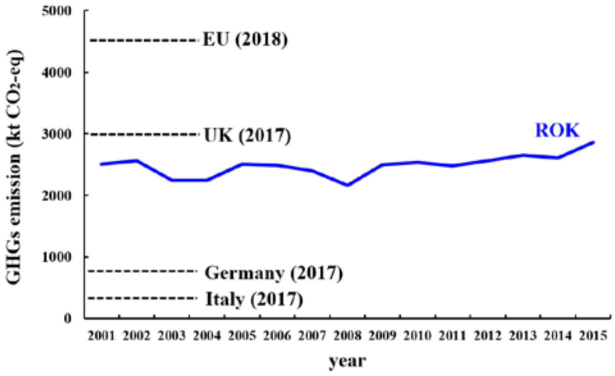

Figure 1: GHG emissions of ROK national defense

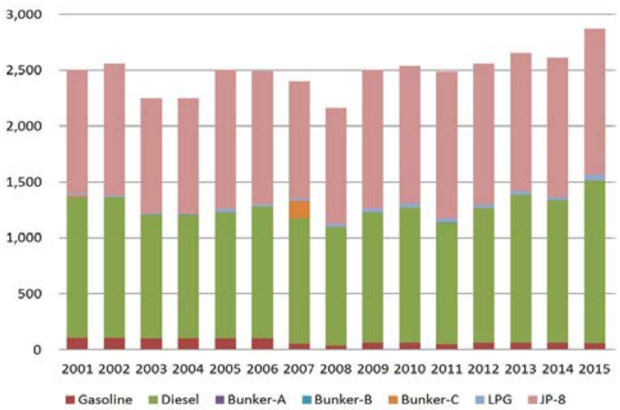

Figure 2: Trend of GHG emissions by fuel type

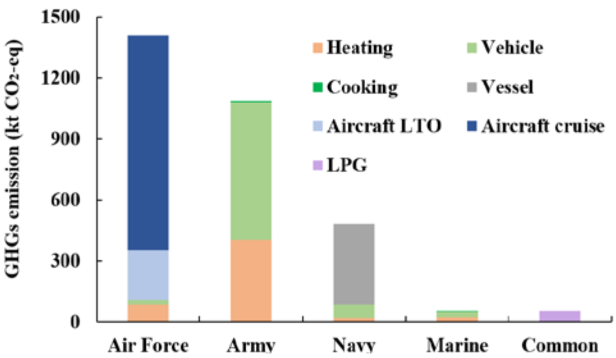

Figure 3: GHG emissions by force and fuel purpose

The limitations of the study were pointed out as follows:

1) insufficient professional review of weapon system characteristics (e.g., data on naval vessels include a significant amount of heating, cooking, and some aircraft activity data), 2) specific emission factors for each equipment and security restrictions when collecting activity data, application method of activity data (area share allocation method, equal distribution, etc.), and 3) omission of the absorbing sources. However, the study by K.-P. Song et al. (2017) is very significant in that the results can be used as basic data for future research.

3.3 Another approach to inventory development for ROK national defense

This section further classifies the sources of GHG emissions and absorptions of the ROK national defense from existing research results, and reports the results of the recalculation of the GHG inventory based on these sources. In Scope 1 (direct emissions), stationary combustion is classified into the forms emitted by the heating and cooling of buildings and cooking, and mobile combustion is classified into the forms emitted from ground vehicles, vessels, and aircraft. Scope 2 (indirect emissions) includes the use of ammunition, GHGs generated during the production of electricity and water, and absorption by standing trees.

The actual oil flow rate and power consumption were used for accurate inventory calculation. Because the use of combat ammunition was extremely small, the training ammunition's data were used to calculate the indirect emission amount due to the use of ammunition in Scope 2. The current state of standing trees investigated by the defense facility information system was reflected as the absorption source. Sewage and waste treatment, soil CO_2 emission and absorption, etc. were excluded owing to the lack of reliability and difficulty of data acquisition. In the military sector, there is also a Scope 3 form of emissions that includes collection and disposal of CO_2 inside a submarine by a chemical method. However, in this way, emissions of CO_2 from a respiratory organ and small emissions of other processes were excluded.

Figures 4-7 show the fuel oil, LNG, LPG procurement amount, ammunition consumption, power usage, and water usage, among the activity data required to calculate the GHG emissions of the ROK national defense (2017–2020). **Figure 8** shows the standing trees data required for the calculation of GHG absorption.

The IPCC emission factors were applied when calculating GHG emissions using activity data according to the amount of fuel used. The formulas for calculating each emission and absorption are provided in **Table 2**.

Because aviation equipment use jet fuel and marine equipment use marine gas oil (MGO), the use of fuels could be clearly classified. However, low-sulfur oil is used for both buildings (heating) and ground vehicles, and LNG and LPG are used for heating, cooking, plant equipment, and ground vehicles. Thus, it is difficult to distinguish the fuel consumption by use. Therefore, based on the application and fuel amount specified in the procurement agency's contract information, the ratio of the fuel amount for building heating, cooking, and equipment for each force were

Table 2: GHG emission and absorption formulas

Source	Formula
Fuel (except LNG and LPG)	(1) Emission (ton/year) = fuel usage(kℓ/year)×net caloric value(kcal/kℓ)×EF(t GHG/TJ)×oxidation rate(0.99)×GWP
LNG and LPG	(2) Emission (ton/year) = gas usage(Nm^3/year)×net caloric value net caloric value(kcal/ Nm^3)×EF(t GHG/TJ)×oxidation rate(0.995)×GWP
Ammunition (indirect emission)	(3) Emission (ton/year) = ammunition usage(round/year)×EF(g GHG/round)×GWP ×10^{-5}
Electricity (indirect emission)	(4) Emission (ton/year) = electricity usage(MWh/year)×EF(0.4567 tCO_2/MWh)×GWP
Water (indirect emission)	(5) Emission (g/year) = water usage (m^3) × EF (332 g CO_2/m^3)
Standing trees (absorption)	(6) Absorption (ton/year) = Standing trees (trees) × Absorption factor (9.36 kg CO_2 / tree·year) × 0.001

quoted. Moreover, after the ratio determined was applied to the low-sulfur oil and gas cases, the GHG emission amounts were calculated.

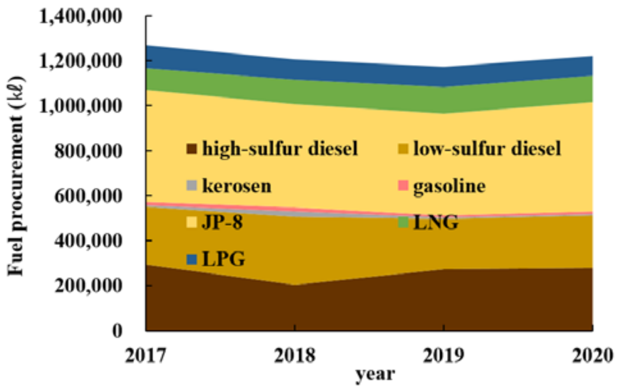

Figure 4: Fuel procurement by ROK national defense

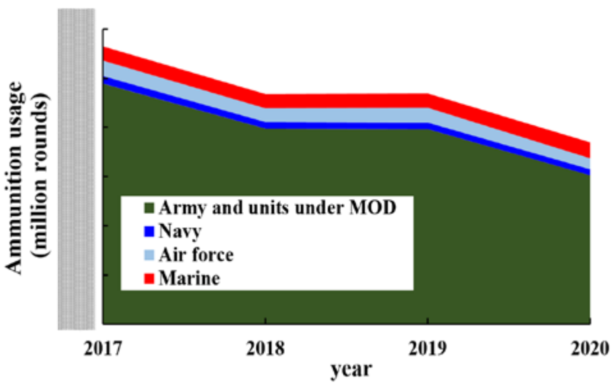

Figure 5: Ammunition usage by ROK national defense

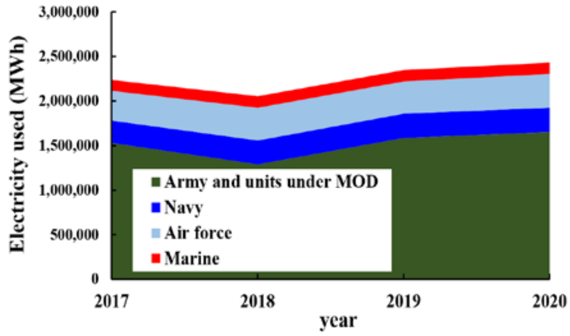

Figure 6: Electricity usage by ROK national defense

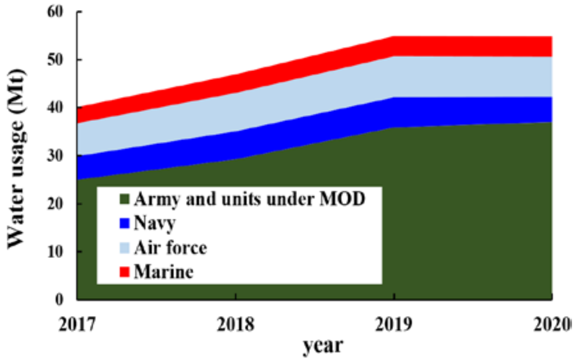

Figure 7: Water usage by ROK national defense

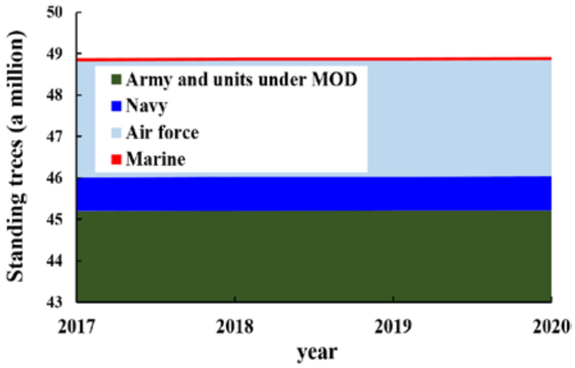

Figure 8: Standing trees of ROK national defense

Indirect emissions were calculated based on ammunition, electricity, and water usage. In the ammunition part, the emission factors presented by US EPA AP-42 **[15]** were used. The emission factors of 152 types of ammunition used by the ROK military were selected and applied separately. Detailed data on the type of ammunition were not disclosed, and strategic weapons, such as Hyun-Mu and classified weapons, were excluded from the calculation in consideration of security. In the power use part, the emission factors **[16]** provided by the GIR were utilized. In the water use part, the emission factor (332 gCO_2/m^3) was applied in accordance with the “Regulations on carbon point system operation” **[17]** of the Ministry of Environment. For forests, which are absorption sources, the average value of the 30-year-old absorption coefficient (9.36 kg CO_2/tree・year), which is the average of the “Standard carbon absorption of major forest water species” **[18]** of the National Forest Science Institute, was applied.

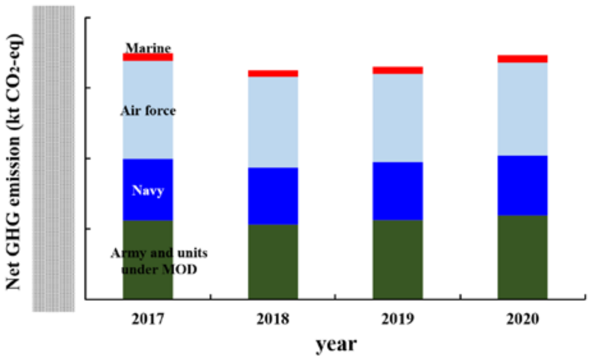

Figure 9: Net GHG emissions of national defense

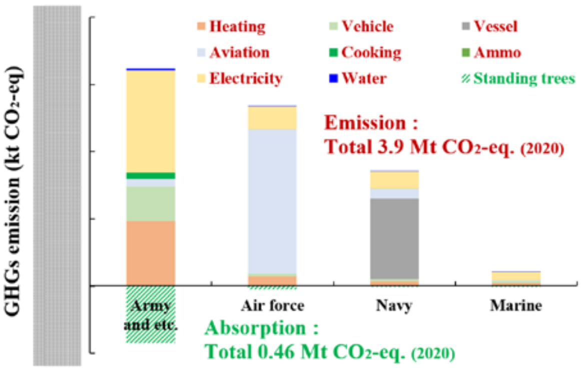

Figure 10: Net GHG emissions of each military force

The GHG inventory of the ROK military sector was calculated for 2017–2020. The net emissions (emissions–absorptions) of GHGs are shown in **Figures 9** and **10**.

Total GHG inventory estimate of the ROK military sector in 2020 is approximately 3.45 Mt CO_2-eq, which is approximately 0.5% of the country's total emissions. Currently, emissions of the military sector account for a relatively small proportion. However, if the government's promotion of carbon-neutral policies in 2050 reduces the total national emissions, it is expected that the GHG emission rate of the military sector will rise significantly. GHGs are emitted in the order of the army (including units under the direct control of the MOD), air force, navy, and marine. Net emissions considering the amount of GHGs absorbed by standing trees are in the order of the air force, army, navy, and marine. Most of the emission sources are the use of aircraft ([redacted]%), which is a direct emission source, and the use of electricity ([redacted]%), which is an indirect emission source, followed by building heating ([redacted]%) and vessel operation ([redacted]%).

The army and marine have the highest GHG emissions from low-sulfur diesel, which is the main fuel for heating and ground vehicles. The navy has the highest GHG emissions from MGO, the fuel for vessels, and for the air force, it is from jet fuel.

Looking at the inventory as a whole, direct emissions account for approximately 71% of the total emissions and indirect emissions account for approximately 29%. The use of fuel oil to activate equipment that are directly related to maintaining the military readiness posture account for more than 50% of the GHGs. The rest is discharged from the power use for maintaining troops and logistic support (maintenance, storage, general service, etc.). The amount of GHG emissions from the use of ammunition is a small proportion of the total. In the case of the army, it has a meaningful result in that the amount of GHGs absorbed by standing trees is significant (approximately [redacted]%).

Two climate change mitigation strategies can be determined from the results of the ROK military's GHG inventory calculation. The first is to gradually change the energy system for national defense. The military's GHG reduction strategies need to focus on the fuel use of aviation, ground equipment, and vessels, which occupy a high inventory, to maximize GHG emission reduction. The second strategy is to improve the energy efficiency of military facilities and the ratio of new renewable energy. It is the second most effective sector in terms of emissions from the use of low-sulfur diesel and electric power in camp facilities (residential, cooking, and business facilities) to maintain military force.

4. Climate change counter measures for national defense

4.1 Alternative energy for low carbon

The priority issue in the military sector's climate-change mitigation policy is a shift to a carbon-neutral energy system. Therefore, it is necessary to convert the fuels of aircraft, ground equipment, and vessels, which make up a significant portion of the military's GHG inventory, into alternative fuels. An alternative fuel for carbon neutrality is a fuel whose total carbon emissions are near zero in the production and consumption processes **[19]**, and it is typically hydrogen, biodiesel, E-fuel, and ammonia. In order for these alternative fuels to be gradually applied to the military equipment related to military readiness posture, they need to satisfy the stability for fuel use and storage, continuity of use of supplying infrastructure, efficiency to meet the required operational capabilities and sustainability of supply in wartime and peacetime, economic feasibility, etc.

In this section, we present the review of the characteristics of hydrogen, biodiesel, E-fuel, and ammonia as alternative fuels in addition to nuclear power, and their applicability to the military sector.

4.1.1 Hydrogen

Renewable energy using wind, solar power, and waste, which is considered preferentially carbon-neutral energy, has fundamental limitations such as intermittent power generation, inflexibility, and regional deviation because it utilizes natural phenomena and industrial by-products. Hydrogen can overcome these limitations and has a higher energy density than renewable energy; therefore, it is in the limelight as a next-generation energy source for major industries.

Hydrogen has already been proven to be applicable as a military fuel, including in the air-independent propulsion used in ROKN submarine type 214. However, there are many challenges to be solved for its expanded application to ground equipment, aircraft, and naval vessels, other than submarines. In particular, in order to store hydrogen for military equipment, temperature maintenance equipment below the liquefaction point and leakage vulnerability solutions (dual storage, fail-safe, etc.) are required. In other words, hydrogen is not sufficiently stable to be applied to military equipment, and to supplement this shortage, the initial cost of equipment increases and the economic efficiency also deteriorates. Considering the cost of importing hydrogen to the ROK, which lacks renewable energy-based green hydrogen production conditions, economic efficiency is not highly evaluated, and the use of by-product hydrogen is not carbon-neutral. In addition, hydrogen-based fuel cells cannot produce the high-power, high-density energy required to operate vessels and large aircraft. It is also difficult to adapt to the gradual fuel system changes because it is impossible to share the use, storage, and supply systems of existing fuels (high-sulfur diesel and jet fuel).

4.1.2 Biodiesel

Biodiesel is made from biological components such as waste cooking oil, rapeseed flowers, and vegetable oils such as soybeans, and in 2015, the ROK stipulated that at least 3% of biodiesel should be mixed with transportation fuel **[20]**. Specifically, unlike hydrogen, it is still used as an additive to existing fuels, such as diesel, and is evaluated as an appropriate alternative fuel for military equipment. The US Navy has also promoted a policy to sustainably increase the amount of biodiesel used in vessels **[21]**, and the Royal Australian Navy and other friendly navies are actively participating in this policy. Because biodiesel can share the existing fuel supply and storage system, it is also advantageous in terms of safety and infra-flexibility, and if unique characteristics such as hygroscopic properties are well managed, the operational performance requirements can be fully satisfied.

However, owing to the following problems, there are many restrictions on increasing the ratio of alternation: a high nitrogen oxide generation rate (20% higher than diesel), food security threats due to damage to cultivated land during the production process, and supply vulnerability (imported biodiesel).

4.1.3 E-fuel (Electric-based fuel)

While the production base of biodiesel is biomass, such as agricultural products, an E-fuel, which is a renewably synthesized fuel, can overcome the limitations of biodiesel in that it is based on recycled carbon. An E-fuel is a hydrocarbon (C_nH_{2n+2})-based artificial fuel (E-methanol, E-gasoline, and E-diesel) created by artificially binding hydrogen to CO and CO_2 based on the Fischer–Tropsch mechanism **[22]** developed in Germany in 1925. During World War II, Germany allocated 9% of military fuel and 25% of civilian vehicle fuel to E-fuels, and German and Japanese automobile companies are still developing E-fuel vehicles. The ROK is also promoting the spread of E-fuel produced based on green hydrogen, centered on the Ministry of Trade, Industry, and Energy **[23]**.

E-fuel generation re-collects the emitted CO_2 and uses it as a base material for fuel. Specifically, CO_2 undergoes a fuel production–use–treatment cycle to achieve carbon neutrality. In particular, the existing fuel use, transfer, and storage systems can be shared, and E-fuels can be used in large vessels and aircraft that are difficult to electrify by energy storage devices. Therefore, they are also attracting great interest in related organizations such as the MOD, navy, and oil refineries **[23]**.

However, there is a problem with economic feasibility. An E-fuel requires considerable electricity for being formed at high temperature and high pressure in the manufacturing process. When viewing the whole process evaluation method, to operate an E-fuel vehicle, seven times the electric power of a pure electric vehicle and three times that of a hydrogen electric vehicle is needed [20]. However, it is very important that national and corporate E-fuel-related projects are underway worldwide, with the research goal of improving the economics of E-fuels to current gasoline levels by 2050.

An E-fuel is an alternative fuel whose base material is a technological capability of a nation. In order to realize energy independence in future climate change crisis situations, it is necessary to secure a high level of E-fuel production technology in the ROK.

4.1.4 Ammonia

Ammonia is sometimes used as a material for transferring and storing hydrogen; however, it is also an alternative fuel that can be burned directly. Ammonia has a higher energy density than hydrogen, a high liquefaction temperature (−33 °C) and a high spontaneous combustion temperature (651 °C), is easy to store, and has stable production and transportation technology. Therefore, the shortcomings of hydrogen can be overcome.

However, ammonia is toxic. Efforts to use ammonia as a fuel for large vessels have been made to a considerable extent [24]; however, like hydrogen, leak vulnerability solutions (dual storage, fail-safe, etc.) are required, and a safety manual should be prepared accordingly. These problems also lower its economic feasibility.

4.1.5 Nuclear power

In July 2022, the ROK government announced that it will increase the proportion of nuclear power plants to respond to climate change **[25]**, strengthen energy security, and create new energy industries. Considering the current supply conditions of renewable energy and alternative fuel infrastructure, it can be stated that the difficulty in replacing fossil fuels in a short period is also in the background.

Nuclear power is not exactly a green energy source, as it produces radioactive waste. However, regarding carbon neutrality, because nuclear power production emits the same level of carbon as wind power generation, nuclear power is being considered as an alternative to fossil fuels. Safety concerns are being gradually reduced by nuclear technology, which has developed for more than 60 years.

However, the application of nuclear power to military equipment is considered only for large equipment that can supply cooling water unlimitedly, such as submarines, aircraft carriers, and naval equipment, and it cannot be applied to ground and aviation equipment.

In addition, applying nuclear power to equipment requires a large budget for acquisition and disposal, and such economic drawbacks can be offset even when an equipment has been in operation for 30 years or more. Moreover, in order to use nuclear power for military equipment, the resolution of international and institutional restrictions is necessary.

Because fossil fuels are the main sources of GHG emissions, it is clear that diversifying the fuel system of military equipment using alternative fuels is a GHG emission-mitigation strategy that the military should promote in the long term. Of the alternative fuels for this purpose, hydrogen and ammonia, which require infrastructural changes in supply, storage, and use and whose safety and economy are reduced, are not suitable for the ROK military. Moreover, nuclear power has a limited range of applications.

Biodiesel is not a long-term option because it emits another GHG, nitrogen oxide, and causes food security threats. The ROK military needs to pay attention to the development trend of E-fuels, and in parallel with long-term investment, it should quickly switch from using a biodiesel system to an alternative fuel system using an E-fuel.

Currently, the economy of E-fuels is insufficient; however, if the economic feasibility is supplemented by the development of technology, it can be immediately applied to most of the equipment used in the military. Therefore, E-fuels can replace fossil fuels quickly.

In terms of the ROK Navy, preparations for the use of nuclear power are also necessary. Small reactor technologies, such as small modular reactors, could be produced in collaboration with industry and academia, and measures and technologies that can be applied to vessels should be prepared. Thus, when an international and institutional background is turned, this will make the conversion to a nuclear system immediately possible.

4.2 New renewable energy for low carbon

Active measures to reduce the stationary emissions from heating and cooking of buildings and the indirect emissions from electricity and water use, which account for a significant portion of the GHG emissions, are also needed. Currently, with the enforcement of mandatory zero-energy public buildings, the introduction of new renewable energy into military facilities is continuing **[26]**. However, it remains at a level that meets the mandatory standards. New renewable energy (considering exposure vulnerability and geothermal energy utilization is suitable) must be actively introduced into major military institutions, such as decision-making institutions, C4I centers, and storage facilities, to provide energy independence for emergencies. Furthermore, it is necessary to formulate a policy for applying energy efficiency improvement technology to general office works, camps, various educational facilities, etc. It should also make the forces participate in the energy efficiency grade certification system when constructing new buildings or remodeling old buildings. It is necessary to expand the application of technologies such as highly efficient heat insulation technology, window door optimization, solar heating, auxiliary power generation systems using solar and wind power, and auxiliary heat source systems, thereby gradually increasing energy independence. The energy independence of military facilities is important because it can achieve the primary effect of mitigating indirect GHG emissions and the secondary effect of energy sustainability.

The topographical, environmental, and industrial characteristics of the areas where military units are stationed must be leveraged to expand the use of available renewable energy. For example, solar power generation facilities on large-scale parking lots, large buildings and facilities, and wind power generation facilities on the coast and islands. Installation of solar and wind power street lights, which is expanded within the local government, can also be a very good starting point.

Certainly, the high initial costs make it difficult to introduce new renewable energy into the military sector. However, the necessity of new renewable energy equipment must be judged from the viewpoints of the GHG reduction effect and life cycle cost, instead of the initial installation cost.

Furthermore, in order to absorb GHGs, it is necessary to maintain and improve the tree preservation rate by constructive management when utilizing a new site and constructing a new facility. Moreover, forestation, park, and solar power generation plant projects at a long-dormant site can also be good alternatives **[27]**.

4.3 Adaptation strategies

Along with mitigation strategies to reduce GHG emissions, the military must also prepare adaptation strategies to address the problems caused by climate change. The military sector's climate change adaptation strategy is in preparation to respond to emerging threats in changed climate, e.g., natural disasters, pandemic such as Corona virus disease-19 (COVID-19), food security, and resource security.

The average sea level in the ROK peninsula has risen by approximately 10 cm in the last 40 years. According to the research of W.-S. Jung (2022), it is expected to rise by up to 65 cm at the end of the 21st century. During this time, piers, including naval bases, will be submerged and coastal infrastructure will be inoperable owing to frequent flooding **[28]**. The above are disasters are expected to be directly caused to the military by climate change. In preparation for such a disaster, the U.S. Navy has been conducting additional reviews when it needs to install facilities and structures near the sea surface. Moreover, it is building new infrastructures on the outskirts of piers and in highlands to prevent flooding damage **[29]**.

According to the United Nations Framework Convention on Climate Change Annual Report 2020, the COVID-19 pandemic is also associated with climate change. Climate change causes the living areas of humans and animals to change and mix, increasing the possibility of virus transmission. Global warming due to GHG emissions not only melts glaciers and raises sea level but also melts permafrost. Moreover, it has been reported that serious problems due to new microorganisms and infectious diseases can occur **[30]**. Infectious diseases are expected to spread rapidly owing to the “globalization” achieved by humankind, and the national selfishness and survival problems expected in this process will renew the security relationship between nations. In addition, considering that infectious diseases have a significant impact on military operations and maintenance of morale, as experienced in the COVID-19 pandemic, the military must not overlook the threat of climate change-induced infectious diseases.

Global climate change and extreme weather events have drawn the world to focus on food and resource security, and countries will demand competitiveness in science and technology to respond to weaponized food and resources. The military is a test stage for national science and technology and will be the end-point of technology application. In this sense, the advancement of military science and technology currently being promoted by the military is a very timely adaptation strategy in terms of the climate change crisis. However, it is necessary not only to develop science and technology focusing on the fourth industrial revolution but also to launch organizations and human resources for research on climate change crisis: scenario prediction, mitigation and adaptation strategies, specific action plans, etc.

4. Conclusion

In the near future, the military will face a new security threat from the climate change crisis. The climate change crisis has increased its threat level at a very rapid rate in 40 years; however, paradoxically, it is still slow to perceive it as a "threat". Considering the vast range and seriousness of the damage that will be faced in the future, participating in specific practical tasks on national global warming issues, institutionalization, and interest in and implementation of military issues of climate crisis are urgently needed.

In this study, GHG policies of the national military sector were reviewed. Although it was not possible to quantitatively analyze the level of the military sector policies and the degree of participation currently underway, it was clear that the military's role in responding to future climate change crises is expanding globally.

Military sector policies must be continually evaluated and complemented by outcomes and effects. Therefore, the GHG emissions inventory calculation is essential. Examples of GHG inventory calculations in the military sector can be found in the USA, UK, and EU, and the range and methodologies of emission sources handled by each country are diverse. In the ROK, a series of studies have calculated GHG inventories of the military sector; however, they are not as transparent and accurate as in other countries. This is because activity data in the military sector are related to the troop's scale and equipment performance, and efforts to calculate inventory may conflict somewhat with military characteristics and confidentiality. In addition, reduction in the military sector's GHGs is not mandatory.

In this study, an attempt was made to calculate the GHG inventory of the ROK military sector by considering the effects of indirect emission sources such as ammunition and absorption sources, which were not covered in existing research. The results are summarized as follows:

1. In 2020, the estimated ROK military total GHG inventory was approximately 3.45 Mt CO_2-eq, which was 0.5% of the total national emissions.
2. GHG emissions are emitted in the order of the army (including units under the direct control of the MOD), air force, navy, and marine.
3. The net GHG inventory considering the amount of GHG absorption is calculated to be high in the order of the air force, army, navy, and marine.
4. Most of the emission sources are the use of aircraft, which is a direct emission source([redacted]%), and the use of electricity, which is an indirect emission source([redacted]%), followed by building heating([redacted]%) and vessel operation([redacted]%).

From the results of inventory calculations, in order to reduce GHG emissions in the military sector, it is necessary to changeover the fuels, enhance the efficiency of military facilities, and improve the utilization of renewable energy. In order to induce a gradual fuel changeover while maintaining the storage, transfer, and usage system of the fuel oil currently in use, an E-fuel as an alternative fuel is suitable for use in consideration of technological development. For military facilities, solar heating and solar and wind power generation facilities must be combined to improve their energy independence.

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It is clarified that the contents of this study are the authors' opinion only and not the official view of the military.

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