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ECO-DESIGN AND ITS TOOLS – ATTEMPTED USE IN THE MILITARY INDUSTRY

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Abstract
The development of military technology in recent years has made tremendous progress. However, some of these technologies have a direct impact on environmental degradation. This makes it necessary to introduce new solutions and technologies in the field of environmental protection. The paper provides a literature review on issues such as eco-design and its tools, life cycle assessment as well as attempted use of them in the defence sector. The environmental regulations and standards ensuring the quality of defence product have been described. In the military industry whose priorities are primarily related to defense the classic approach to design and its tools focused its attention on safety, functionality, ergonomics, costs, strength and technical parameters, instead of environmental problems. In fact militarism has huge impact on the climate because of giant greenhouse gas emissions, the main problem of the Armed Forces is the increased carbon footprint emissions which should be reduce of therefore case studies of eco-design and its tools, commercial software tools for carbon footprint calculation and life cycle assessment are described.
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Keywords: **Carbon footprint; Computer systems for eco-friendly design; Eco-design; Eco-design tools; LCA life cycle assessment.**

1. INTRODUCTION

Eco-design compared to classical technical design introduces two additional elements of design evaluation:

– An environmental impact assessment, as well as
– Life-cycle perspective [1]

Unlike a conventional approach, it is defined as "any form of project that minimizes environmental impact by means of integration with life processes". In order to connect ecology and design, existing design of products, buildings and landscapes should be enriched with a detailed understanding of the concept of ecology [2].

Eco-design defines the environmental impact of a product that takes into account environmental aspects at an early stage of design [3]. It aims to construct products that will have the least impact on the environment throughout their life cycle [4, 5].

The literature also includes other terms for eco-design: Design for Environment (DFE), Ecological Design – Green Design, Life Cycle Design, Environmental Design, as well as Sustainable Product Design [1, 6, 7, 8].

DFE takes into account all environmental factors that occur in the various stages of product formation, i.e. design and development. It aims to minimize the negative environmental impact of the product [9, 10, 11].

DFE elements are i.e. Design for Disassembly, Design for Recycling (DFR), Design for Remanufacturing (DFR), Design for Longevity and Design for Packaging (DFP).

Tools that can support eco design product at an early stage of project development include the following methods: QFD and FMEA, DFMA and DOE.

QFD (Quality Function Deployment) is a method of developing product quality that allows both the design of the quality of new choices as well as the improvement of the quality of existing ones, with a special focus on the customer's needs and requirements.

The FMEA (Failure Mode and Effects Analysis) method allows predicting the probability of errors and then determining the causes of errors.

On this basis, preventive measures can be developed to eliminate errors or minimize the probability of errors ocure during the design, manufacture and use of the product.

DFMA (Design for Manufacture and Assembly) is a methodology that focuses on reducting time of plcing the product on the market and total production costs. DFMA method enables i.a. decreasing the cost of assembly of the product as well as the total cost of manufacturing parts by simplifying this design, as well as choosing the most efficient technology.

The Design of Experiments (DOE) method focuses on obtaining as much valuable and reliable information as possible about the product or process by means of the smallest number of experiments [10, 12].

Sustainable products design is a broad concept with environmental and social elements. Unlike traditional design, it also provides an assessment of the project in terms of its environmental impact [13]. Design problems such as how to design production processes and products so that all materials can be fully recovered can only be solved if industrial designers will consult them with biologists, architects, physicists, farmers, environmentalists at the design stage [1]. In this way, they will be able to select the right materials (raw materials), focus their attention on maximizing the efficiency of the equipment and the recyclability at the end of the product life cycle to being able to achieve the greatest ecological effect at the very design stage [14].

2. ENVIRONMENT AND MILITARY INDUSTRY

The Armed Forces of the Republic of Poland are subject to the environmental regulations in force in the area of civil law. The basic environmental protection measures include [15]:

- Regulation of the Minister of National Defense of 26 April 2004 on the definition of bodies responsible for supervising compliance with environmental regulations in military units and other organizational units subordinated to or supervised by the Minister of Defense [16].
- Directive No 57/MON of the Minister of National Defense of 23 December 2002 on the definition of the organizational units responsible for supervising of compliance with environmental regulations in the Armed Forces [17].
- Agreement between the States Parties to the North Atlantic Treaty concerning the status of their forces, done in London on 19 June 1951 [18].
- Agreement between the States Parties to the North Atlantic Treaty and other states participating in the Partnership for Peace [19].

In accordance with the legal acts describing environmental and waste management proceedings by military units, actions are implemented that ensure the protective life and health of people and the protection of the environment in accordance with proper waste management. Nevertheless, further action by military units is needed to reduce waste, increase the share of waste to be recovered and disposed of, and treatment of hazardous waste, where they were created [15].

The military industry has quality systems known in the world; they allow military and civilian companies to contract with the participation of Armed Forces of the Republic of Poland/North Atlantic Treaty Organization.

On the website of the Military Centre for Standardization, Quality and Codification there can be found documents that standardize the functioning of the quality assurance system [20]:

- Decision No 126/MON of the Minister of National Defense, dated 16 August 2019 on the quality assurance of military equipment and services for military equipment, (item 159),
- STANAG 4107 – Mutual Acceptance of Government Quality Assurance and Usage of the Allied Quality Assurance Publications (AQAP),
- AQAP 2070 – NATO's Process for Mutual Implementation of Government Quality Assurance (GQA).

AQAP (Allied Quality Assurance Publication) are the standards for quality assurance systems that have been develped by NATO. They are designed to define standards to ensure the quality of defense products. These standards are described in the STANAG 4107 standardization agreement. Currently, we can distinguish two main types of AQAP documents [21]:

- Documents of a contractual nature, recorded in the form of technical specifications intended for contractual use.

- Instructions with general guidelines

Current AQAP publications include [22]:

- AQAP 2131:2006 – "NATO Quality Assurance Requirements for Final Inspection" – doesn't include ISO 9001 requirements apply to final product quality control.
- AQAP 2130:2009 – "NATO Quality Assurance Requirements for Inspection and Test" – include ISO 9001 requirements, concerns final product control, quality control in the production process and quality of delivery of a product (or its parts).
- AQAP 2120:2009 – "NATO Quality Assurance Requirements for Production" – includes ISO 9001 requirements, extension of AQAP 2130 requirements to the quality of assembly, service and commissioning of the product.
- AQAP 2110:2009 – "NATO Quality Assurance Requirements for Design, Development and Production" – includes ISO 9001 requirements, extension of AQAP 2120 requirements for supervision on the product design.
- AQAP 2105:2009 – "NATO Quality Assurance Requirements for Deliverable Quality Plants" – does not include ISO 9001 requirements applies to quality plans for the final product.
- AQAP 2210:2006 – "NATO Suplementary Software Quality Assurance Requirements to AQAP 2110" – does not include ISO 9001 requirements, extension of AQAP 2110 requirements with quality requirements for product software.

3. TOOLS TO SUPPORT ECO-DESIGN IN THE MILITARY INDUSTRY

Knowledge of the life cycle of the product "from cradle to grave" enables efficient management. The life cycle of weapons systems in the Polish armed forces in its general overview is in accordance with the life cycle of natural systems (living and nonliving).

In order to introduce eco-design into the military industry, it is necessary to identify environmental and social aspects in the product design and development process, which includes processes such as conceptual design, detailed design, prototype testing, production preparation (structural/technological/organizational), production process, use as well as recovery and disposal [23, 24, 25].

The tools that help to achieve the above objectives are Life Cycle Assessment (LCA) also known as Life Cycle Analysis (LCA), as well as Product Environmental Declarations which help to compare the environmental impact of products with different functions and technical solutions. The widely recognized procedures for the Life Cycle Assasment method are described in a series of environmental management standards ISO 14040 and ISO 14044 [26, 27] and ISO 14048 [28] and ISO 14049 [29].

Environmental, social and financial aspects can be taken into account in the Life Cycle Assessment.

Environmental aspects are assessed using the LCA (Life Cycle Assessment) method, social aspects using S-LCA (Social Life Cycle Assessment) and economic aspects using E-LCC (environmental life cycle costing).

Life cycle analysis (LCA) is one of the most popular eco-design tools but also the most complex. The LCA evaluates the environmental impact of a product, service, or process. The analysis covers the life cycle i.e. extraction and processing of raw materials, production, distribution, use, recycling and disposal. The LCA analysis according to ISO 14040 and 14044 consists of the following stages:

– defining the purpose and scope, includes key decisions to determine whole stages of study. At this stage, the purpose and scope are selected; functions, functional units, system limitations and reviews are defined.
– analysis of the set of inputs and outputs (LCI), i.e. analysis of the inventory set (including process models, compilation of data on the consumption of natural resources and emissions during the life cycle of the product).
– Life-cycle impact assessment (LCIA) on the environment.
– And interpretation [26, 27, 30].

Based on the LCA method, it can be analyzed which element in product lifecycle is the most problematic. The main objective of the LCA method is to find all factors that have a potential impact on the environment as well as factors related to product or process, while the result is to determine the environmental impact of the product system or process in the area of resource consumption, ecosystem quality and human health [31].

Life cycle assessment (LCA) can be used in conjunction with ammunition emissions data to quantify environmental influence of military training activities. The aim of LCA method is to investigate contributing factors to environmental toxicity of emissions to reduce their environmental impact. For this purpose a combination of emissions data, experimental data and predictive modelling software can be used [32].

Social life cycle assessment (S-LCA) method assess the social and socio-economic aspects of products, their positive as well as negative impacts along the full life cycle (extraction and processing of raw materials, manufacturing, distribution, use, reuse, maintenance, recycling and final disposal). The framework detailed in the S-LCA guidelines is in line with the ISO 14040 and 14044 standards for Life Cycle Assessment. Adaptations for the consideration of social and socio-economic matters are described in the structure. S-LCA doesn't provide information on the question of whether a product should be produced or not – although information obtained from an S-LCA can be helpful for taking this decision. S-LCA methode may be conducted on any products, even those that are knowingly harmful to society (e.g. weapons in the military industry). This method is recommended to be used ethically. It is assumed that review of aspects will prevent using the methodology inappropriately [33].

Environmental Life Cycle Costing (E-LCC) method allows determining the relationship between the potential product's influence on the environment and related costs. In the literature this method is classified as one of the modern cost calculus, however there is no consistent definition. LCC must be used as a point of reference against which options can be measured as "value for money" during the acquisition process, keeping in mind that the greater possibilities to reduce LCC usually occur during the early phases of the programme. In the search of the best compromise between time, cost and performance LCC is used as a decision and optimization criterion. Despite life cycle costing is internationally considered as instrument for estimating investments in military equipment its practical use remains insufficiently researched. Life cycle cost estimates of defence programmes are inherently uncertain and risky. Very often information and data are sparse therfore estimates are based on historical samples of data that are oft messy, limited, difficult and costly to obtain. For this reason no matter what estimation tool or method is used, the weapon system under study is often of sketchy design [34, 35, 36, 37].

Another important indicator including economy in LCA is eco-efficiency. It is a quantitative management tool that enables the investigation of live cycle environmental influence of a product system. ISO 14045:2012 describes the principles, requirements and guidelines for eco-efficiency assessment for product. The analysis of eco-efficiency becomes closely connected to LCA regarding the environmental scope. Nevertheless, to determine the eco-efficiency of products, LCA has to be combined with LCC for that to cover both the economic and ecological scope of eco-efficiency for the same product system limit. Eco-efficiency shares with LCA many important principles such as life cycle perspective, comprehensiveness, functional unit approach, iterative nature, transparency and priority of a scientific approach [38, 39, 40].

To assess life cycle impact of the product a number of metods are avaiable [41]. The most frequently applied are the three methods: Ecoindicator' 99 [42], EDIP97 [43], CML2001 [44]. Comparision of these three LCIA methods show that EDIP97 and CML 2001 are both similar in their scope and structure [45]. The third impact assasment method Eco-indicator 99 is different in scope and structure from the other two. And is used to assess the life cycle of the product, simplifying the damage categories to three basics: human health, ecosystem quality and resource reduction. This method was introduced in the form of software systems supporting the ecological evaluation of product development in the product life cycle [46].

Another very important aspect is the calculation of the carbon footprint. A carbon footprint is the sum of gas emissions during the full life cycle of a product (company). This concept refers to emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases. It is expressed as carbon dioxide equivalent per functional unit of the product. Trades around the world are striving to reduce greenhouse gas emissions. The search for tools to determine the environmental impact of a product has led to the idea of carbon footprint. More and more entrepreneurs are choosing to calculate the carbon footprint, however, in Poland its calculation is used mainly by international companies as well as by those, who have a contractor in the supply chain who requires the determination of the size of the carbon footprint [47, 48].

Nowadays, there are a number of computer systems supporting eco-friendly design. One of them is ECODESIGN PILOT. This program combines ecodesign with the product development process. It is a tool allowing precise calculation of potential actions which have the greatest impact on the environmental quality of the product with the lowest risk of implementation. The semi-quantitative analysis in this program consists of three stages. The first step involves determining the type of the analyzed product where can be classified, second the selection of right strategies and the last step is completion the checklists to obtain the most efficient eco-design task with the lowest risk factor [49]. It is a free program available on the website [50].

The next software is Open LCA. It is high-performance software that quickly and reliably calculates the assessment of sustainability and life cycle. Life cycle estimates and social assessment are integrated into the life cycle model. This program identifies the main factors in the whole life cycle according to process category or flow [51].

The software used for quick calculation of the carbon footprint is the "LCA Calculator" program; it is designed for designers and engineers, helps to understand quickly and intuitively, analyze and conduct life cycle analysis and then compare the impact of their products and individual decisions on the environment. It provides sustainable design solutions [52].

The main problem is that most of the computer programs used to calculate the carbon footprint doesn't really work in the military sector. This is due to the fact that these programs are designed for devices/vehicles in everyday life not for military vehicles for example warships, jets, tanks, fighter planes which are the major consumer of fossli fuels. The table bellow shows an example of carbon emmision for selected military vehicles.

Table 1.
Carbon emmisions of selected military vehicles [53]

Vehicle	Fuel efficiency (miles per gallon)	Carbon emmision per mission (use only)
Armured truck	6 mpg	260 kg CO_2e
Combat plane	0.6 mpg	27.800 kg CO_2e
Nuclear-armed plane	0.3 mpg	251.400 kg CO_2e

For comparision, the average new diesel car is rated at nearly 60 mpg [54]. Therefore, the military carbon footprint calculation programs should be adjusted to obtain reliable results.

4. CASE STUDIES OF ECO-DESIGN AND ITS TOOLS

The development of military technologies over the last decade has made great progress. However, some of these technologies have a direct impact on environmental degradation. The armed forces are a "biggest carbon emitter and serial oil user". This is due to the need for mobility and use of vehicles in places with extreme temperatures. Crawford's report describes ways to reduce carbons footprint emissions in the armed forces by developing plans for each military installation to reduce energy consumption [53]. "There is a lot of room here to reduce emissions", Crawford said.

Crawford's report shows a few ways to reduce carbon footprint in the military for emple:

- preparing plans for each military installation to reduce its energy use
- making its vehicles more efficient
- moving to cleaner sources of energy at bases
- green up military
- to move away from consuming so much fuel by pushing for more transparency how the military use their fuel, what portion of their consumption is actually for training or air shows that may or may not be necessary.
- to close some bases or to convert them into renewable energy sites for wind and solar.

The U.S. military, the world's largest single energy consumer, is producing a huge carbon footprint. In 2013, the Pentagon reported that fuel consumption by the Pentagon was 80% of the federal government's total consumption. The fuel used for jet engines produces about 39 million metric tons of carbon dioxide. For example just one of the military's jets, consumes about as much fuel in an hour as the average car driver uses in seven years. The Earth has become a "silent victim of war" where ecosystems and habitats are destroyed [55].

The storage of military vehicles, aircraft, helicopters, unused ammunition, etc. is also a huge problem. An example is the "Arizona Cemetery", with about 4, 400 aircraft and helicopters on 11 square kilometers, and the Sierra Military Base serving as a storage facility for U.S. army vehicles.

Elizabeth Warren, Democratic politician, recently released a decade-long defense research program focusing on micro network and advanced energy storage. The plan aims to decarbonize the military, meaning that the Pentagon will achieve net-zero carbon emissions for all its non-combat bases and infrastructure by the end of 2030 and commit bilions of dolars to new Pentagon energy efficiency research [56].

In the paper [57] the life cycle greenhouse gas emissions in the Norwegian defence sector has been assessed. The study shows that organisational life cycle assessment provides an effective instrument to map greenhouse gas from a large and complex organisation such as the Norwegian defence sector. Applying a hybrid attempt by using both process and economic LCA allows the calculations to capture both user and supply interphases without extensive collection of inventory data. In this way military sector can develop strategies to reduce greenhouse gas emmision.

Militarism is the elephant in the room of global warming. Of all government sectors, "Defence" has the highest carbon footprint and expenditure, yet has largely been exempt from international scrutiny and regulation. Marty Branagan describes Australian and international case studies in order to show that non-violence is an alternative to militarism for national defence [58].

Also energy considerations for long time have an essential meaning to carrying out the mission of armed forces worldwide. These include land, air, water transport installations and forward operating locations. Reducing and diversifying fuel use are also factors having economic considerations of military energy use. Paths that strengthen environmental performance objectives should be choosen by defence policy makers [59, 60].

Departament of defence needs to significantly change how it uses and manages facilities energy.

To do this the department has set three related goals:

1) Reduce energy usage and intensity.
2) Increase renewable and on-site energy generation (distributed generation).
3) Improve energy security [61].

5. SUMMARY

The main problem of the Armed forces is the increased carbon footprint emissions. Most of the above-mentioned eco-design methods could be used in the military industry to reduce carbon emissions. The use of computer systems such as ECODESIGN PILOT, Ecoindicator'99 and carbon footprint calculation programs such as the LCA Calculator would certainly significantly reduce the carbon footprint, but it is necessary to adapt these programs to defensive products.

Also note worthy are the ways in which carbon footprint emissions are reduced, as described in the Crawford report, which are designed for all military installation to reduce energy consumption. It is also noteworthy Elizabeth Warren's 10-year military decarbonization research program. Solar energy, electric vevicles or aspirations of "carbon neutrality" may promise fuel efficiency but there is very difficult to find a comparable alternative to energy-dense jet-fuel so achieving net-zero carbon emissions wiil be very dificult to achiev due to the nature of the military industry but it can definietly be limited e.g. by power military bases or even drones with solar energy.

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