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BUILDING TOMORROW: ADDITIVE MANUFACTURING UNLEASHING SUSTAINABLE PROGRESS IN THE US MILITARY

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Abstract. Additive manufacturing (AM) has recently attracted the attention of academia and private companies, viewing it as a tool for achieving sustainability within the context of sustainable development (SD). As the previous studies revealed an ongoing debate on the sustainable nature of AM, making it challenging to conclude, the primary objective of this article is to explore new perspectives that enhance the contribution of AM to the sustainability vision. Given the limited number of studies considering the potential contribution of AM to specific Sustainable Development Goals (SDGs) and associated targets, this research aims to complete the existing body of knowledge through an in-depth analysis. Furthermore, recognizing that AM could generate some unsustainable effects from a security standpoint, this study investigates how the military organization, with its capacity to mitigate such concerns, could contribute to implementing specific SDGs and targets through AM small and large-scale adoption. Therefore, the study follows a qualitative approach, studying the case of the American military forces in an attempt to reveal the main reasons for adopting AM and the possible contribution to specific SDGs and targets. The results highlight a consistent potential for the US military to contribute to SD, mainly through the large-scale adoption of AM. This measure could reduce their military logistic footprint and provide financial, operational and strategic advantages. While the main findings are presented in a detailed list which supports these conclusions and offers valuable lessons learned, it is essential to acknowledge the limitations of this research – namely, the lack of quantitative evidence. Therefore, to formulate a conclusive judgment on the sustainable nature of AM, future studies should concentrate on assessing financial data from private and public entities, including military organizations.

Keywords: additive manufacturing; sustainability; Sustainable Development Goals; targets; U.S.; military

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1. Introduction

Sustainability, the ultimate purpose of Sustainable Development (SD) (Blewitt, 2018, p. 41), has emerged as one of the most substantial reasons for adopting additive manufacturing (AM), which is utilized by the private sector as a tool to achieve both competitive advantages and optimization (Sonnenburg, 2022). The existing body of literature offers numerous examples crediting this emerging disruptive technology (Leonardo, Del Prete, 2022, p. 1) for sustainability efforts. However, only some researchers have analyzed the contribution AM technology

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could make toward specific Sustainable Development Goals (SDGs), and their assessments highlight the possibility that AM sustainable impact will be greater. Therefore, the main objective of this article is to explore new prospects of AM sustainable potential, with a focus on additional private and public sectors, completing the picture of private contribution to the implementation of SDGs and their subsequent targets, as defined by the United Nations. It should be noted that the SDGs and targets were proposed by this international organization in 2015, establishing 2030 as a deadline for their implementation (United Nations, 2015, pp. 13-27). Consequently, each actor that can contribute to an extent to this endeavor is more than welcome.

The research unfolds in two main steps. In the initial phase, the actual state of knowledge was reviewed, revealing the imperative for a more detailed analysis of the AM sustainable potential. This involves considering specific SDGs and their associated targets, not only from the perspective of private companies but also from that of public actors. Moreover, the review highlighted that AM adoption does not guarantee sustainability in any condition, posing a real threat to security. Recognizing that public organizations, such as the military, possess tools to prevent and mitigate these unsustainable effects, the subsequent step of the research is dedicated to an exploratory case study on the potential contribution of the US military to security and sustainability through AM adoption. This qualitative approach aims to answer two research questions: 1) Why are the American military forces interested in AM technology? 2) How do the American military forces contribute to implementing specific SDGs and associated targets through AM adoption?

The answers to the two formulated questions are provided in the subsequent sections of the case study. These unfold within the context of joint efforts to develop AM technology at an industrial level in Guam - a remote location in the USA, which also holds the potential of serving as a strategic military hub in the Asia-Pacific region (Brice et al., 2023, pp. 28-29). As a result, the main output of this scientific approach is presented as a list outlining the sustainable effects that the military forces could achieve through the implementation of this project. At the same time, the associated contributions to specific SDGs and targets are also detailed. The article introduces a new perspective, completing the existing research framework with military insight.

For the space economy, the *short titles of SDGs* (United Nations, 2023) are used within this article, and they are mentioned mostly when a certain SDG is referred to for the first time. For the same reason, it is noteworthy that all descriptions and ideas associated with the content of SDGs and targets are taken from the UN 2030 Agenda for SD (United Nations, 2015, pp. 14-27).

2. Literature review on the contribution of AM technology to Sustainable Development Goals

Most writings on AM sustainability highlight its economic, environmental and social benefits, but they often do not specify which SDG they align with. A more effective approach involves analyzing each SDG and its corresponding targets to understand how exactly AM contributes to sustainability. However, to our knowledge, only two notable scientific contributions directly explore how AM technology can help achieve specific SDGs outlined by the United Nations in 2015 (United Nations, 2015, pp. 14-27). One study from 2019 delves into several dimensions identified in the literature as generating sustainable benefits through AM, such as: enhanced cooperation among different stakeholders, improved health and safe conditions for workers, education and training, pollution prevention, enhanced performance of products, sustainable consumption of energy and raw materials and lighter supply chains (Machado et al., 2019, p. 484).

When it comes to fostering greater collaboration, authors point out that SDG 8 – "*Decent work and economic growth*", SDG 12 – "*Responsible consumption and production*", and SDG 17 – "*Partnerships for the goals*" could be implemented more easily if solutions offered by reverse logistics, remanufacturing, efficiency during production and usage phases (minimized waste and energy). Customer involvement was considered when establishing a company's strategy (Machado et al., 2019, p. 486). The analysis also highlights some indirect

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benefits to workers' health and safety due to the simplified production process, which involves less welding and exposure to toxic substances (Machado et al., 2019, p. 485), revealing a possible contribution to SDG 3 – "*Good health and wellbeing"*, though it is not explicitly mentioned.

From the standpoint of products obtained through AM, the sustainable benefits are linked to improved quality associated with materials and weight reduction, extended durability, the capacity to be reintroduced in the manufacturing cycle and produced where needed, lighter logistic burden and, thus, reduced pollution (Machado et al., 2019, p. 485). According to the authors, there are seven SDGs which are positively impacted in this case, namely SDG 8, SDG 9 – "*Industry, innovation, and infrastructure"*, SDG 11 – "*Sustainable cities and communities"*, SDG 12, SDG 13 – "*Climate action"*, SDG 15 – "*Life on land"* and SDG 17 (Machado et al., 2019, p. 485).

Regarding the impact of a simplified and resilient supply chain, the main arguments which support AM's contribution to SDGs 9, 11, 12, 14 – "*Life below water"* and 17, consist of reverse logistics enablement, shorter transportation routes and cooperation between industry and customers (Machado et al., 2019, p. 485). Additionally, the dimension of training and education reveals some promising prospects of adopting AM technology, particularly in the social aspect of employment, as the new approach in manufacturing requires different educational paths, supporting this way SDG 4 – "*Quality education"* (Machado et al., 2019, p. 486).

As the fourteen companies analyzed by authors reveal sustainable practices across dimensions taken into consideration, the study suggests that the benefits of AM can directly or indirectly contribute to a broad spectrum of SDGs and targets (Machado et al., 2019, p. 484). Thus, a comprehensive overview indicates that AM could positively influence ten out of seventeen SDGs (59%).

Published this year, the other study, which also focused on AM's contribution to SDGs implementation, revealed some more optimistic expectations. Following an exploratory literature review, the authors found that AM has high influence on six SDGs (1 – "*No poverty"*, 3, 4, 9, 12, 14), a moderate effect on two SDGs (7 – "*Affordable and clean energy"*, 10 – "*Reduced inequalities"*) and a low influence on other four SDGs (2 – "*Zero hunger"*, 5 – "*Gender equality"*, 6 – "*Clean water and sanitation"*, 13). Meanwhile, SDGs 15, 16 – "*Peace, justice, and strong institutions"*, and 17 were reported as not positively influenced by AM (Muth et al., 2023, p. 2). What is more, the authors of the study could not reach a conclusion related to AM contribution to SDGs 8 – "*Decent work and economic growth"* and 11 – "*Sustainable cities and communities"*, highlighting the need for future studies in these areas (Muth et al., 2023, pp. 7-9). This latest study added to our knowledge of AM contribution to SDGs in four ways: discovering new potential for sustainability (SDGs 1-7, 10), confirming the results of the former study (SDGs 9, 12, 13, 14), contradicting some of the previous findings (SDGs 15, 16, 17), and expressing doubts about AM sustainable potential (SDGs 8, 11).

Compared to the previous study, the recent one considered a more significant number of SDGs positively impacted by AM technology adoption (twelve out of seventeen – 71%). Although the degree of contribution varies, AM has a growing potential to influence more SDGs. This evolution is likely due to the rapid discovery of new ways to integrate AM into the vision of SD, driven by technological progress. Given the increasing interest in the sustainability of AM, it is worth considering that the impact of this technology on SD could be even more significant. That is why it can be hypothesized that a more detailed assessment, focused on the 169 SDGs targets (United Nations, 2015, pp. 13-27), might offer a more realistic understanding of AM sustainability.

Consequently, building on the conclusions developed by the authors of the later study, who state the impossibility of evaluating the enhanced contribution AM could have on the accessibility of sufficient food sources (Muth et al., 2023, p. 4), the literature review continues with the analysis of other studies, to complete the AM contribution to sustainability. However, these studies do not explicitly mention the impact of specific SDGs. As other studies

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reflect the increased interest in alternative sources of food and the wide range of possibilities in this respect, and some companies and public players allocate funds to integrate AM solutions for food production (Sher, 2021), it can be estimated that in the future, "algae, mycoproteins, cultured meat, plant proteins, and insects" (Van Huis, 2020, pp. 965-966) will be quickly processed through AM. This could complement the environmental benefits of AM, mainly because these alternative food sources have become more readily accepted. For instance, mealworms "produce fewer greenhouse gases and require less land than chickens, pigs and cattle" (Oonincx, De Boer, 2012). To grasp the urgency of changing our approach to nutrition needs, it is notable that between 2000 and 2022, greenhouse gases (GHGs) emissions from farming increased by 13%, more than half attributed to livestock, while the agricultural land decreased by 134 million ha (Food and Agriculture Organization, 2022, p. 3). What is more, as the food demand for meat is estimated to increase by 15% by 2032 (OECD-FAO, 2023, p. 188), these challenges could be addressed by consuming 3D printed alternative food products, cheaper and healthier than traditional options, already validated during space operations (VoxelMatters, 2023, pp. 21-22). Thus, AM could have a significant contribution not only to SDG 2 – "*Zero hunger*", but also to SDG 3 – "*Good health and well-being*" and SDG 13 – "*Climate action*".

Another area in which AM could significantly contribute to SDG 6 – "*Clean water and sanitation*" is the increased access to drinking water. Although the authors of the later study attributed a low potential of AM in this regard, the availability of this technology in remote areas could lead to reduced prices, as prices decrease with an increase in supply, in accordance with the law of supply and demand (Kramer, 2023). Additionally, examples of AM applications in water treatment, such as microrobots designed to clean polluted and toxic natural and man-made water sources, provide a compelling argument for the positive impact of this technology, not only on SDG 6, but also on SDG 3. The innovation brought to the medical sector may also be considered, as biomedical applications involve microrobots capable of reaching difficult areas within the human body without rejection by the immune system (Dabbagh et al., 2022). From these perspectives, an unexpected influence could extend to SDG 15 – "*Life on land*", considered to be supported by AM in the former study but assessed with no sustainability chance by the latter. The very thing that AM makes possible is that new food sources come from alternative sources in the marine ecosystem, and laboratories decrease the pressure on land-based resources, slowing down biodiversity loss. Moreover, microrobots play a role in reducing the toxicity of natural waters, preventing the development of "alien species" invasion, and contributing further to SDG 15 (United Nations, 2015, p. 25).

In close alignment with the aforementioned points, the third argument supporting a greater contribution of AM to the sustainability vision revolves around reducing greenhouse GHGs emissions. Despite the lack of robust evidence, as claimed by the authors of the later study regarding AM contribution to SDG 13 – "*Climate action*", a compelling example emerges in the context of AM sustaining alternative food sources that concurrently have the potential to curtail GHGs emissions.

Besides this, AM potential to contribute to SD is given by numerous other examples. Notably, AM contribution to the environmental dimension of SD gained a lot of attention lately. While researchers still debate whether AM is more sustainable than conventional manufacturing (CM), private companies have proposed tools to enhance the sustainable dimension of AM. For example, although researchers acknowledge that AM environmental friendliness depends on factors such as the life cycle stage of the product (Tadesse, Durieux, Duc, 2020, p. 22), the nature of raw materials (Sanchez-Rexach et al., 2020, pp. 7105-7119) or other factors, there can be taken four steps to improve AM contribution to a decreased environmental footprint: 1) ensuring transparency of materials and processes; 2) developing a comprehensive database to provide sustainable information about each product life cycle stage; 3) predicting environmental impact before 3D printing; and 4) enhancing recycling efforts (Langefeld et al., 2022, pp. 2-7). As this roadmap was developed to assess energy usage, the diminished consumption of energy resources could serve as a pivotal driver for the broader adoption of AM and, consequently, a more significant impact on SD.

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This idea aligns with the prospects that "carbon emission goals can only be reached if the overall energy consumption is reduced at the same time" (Wycisk et al., 2022, p. 6), lending significant value to the aforementioned roadmap. Furthermore, the distinctive value that AM adds to this dimension is given by another instrument offered by private sector for the calculation of CO_2 footprint, which takes into account energy consumption in every step of the production process, with different combinations of alloy and manufacturing routes, to choose the best environmental option which gives AM superiority over the CM (Wycisk et al., 2022, pp. 9-17). Apart from this sustainability interest, private companies also manifest the need to reduce energy consumption, which will translate into lower prices for their products and foster competitive advantage and the economic dimension of sustainability. For instance, the results of a study show that AM could bring savings of maximum 27% in industrial energy consumption by 2050 (Verhoef et al., 2018, pp. 349-360). Hence, the prospects are favorable for finding and encouraging sustainable AM solutions in this respect.

From the social dimension perspective, apart from the already mentioned contributions, AM holds the potential to instigate profound changes in tomorrow's society. The four steps outlined above, aimed at reducing the environmental impact through digital sources of sustainable information, could pave the way for a shift from expert know-how to data-driven decision-making (Langefeld et al., 2022, p. 8). Additionally, the wide range of production possibilities brought by AM could reduce globalization and foster the local supply chains (Langefeld et al., 2022, p. 8) while promoting social justice as the production becomes accessible to a larger part of the population (Coblens, 2022). This trend aligns with the prevailing sentiment among consumers, as two-thirds prioritize environmental and social challenges over economic concerns (Coblens, 2022). Other important social changes AM could include transforming consumers into prosumers and encouraging increased engagement with societal needs contingent upon responsible production and consumption activities (Ford, Despeisse, 2016, pp. 13-22). An essential role in this regard belongs to education and training programs, which have the potential to bolster AM sustainability knowledge while offering new skills and reshaping the occupational landscape (Masurtschak, Almeida, 2021, pp. 2-4), at the same time, a valuable contribution to SDG 4 – "*Quality education*".

Apart from the numerous sustainability arguments presented in the reviewed literature, some studies set the alarm on AM's threat to SD. Examples from the security domain reveal the unsustainable potential of this emerging technology. For instance, despite the positive economic contributions AM makes to the development of next-generation nuclear reactors and the extended life cycle of older nuclear plants (Sher, 2022) - offering a viable solution for obsolete parts no longer available on the market - the darker side of AM lies in its potential to facilitate illegal and autonomous production of a wide range of weapons. These include missiles, nuclear weapons, bullets, and chemical explosives (Fey, 2017, pp. 21-30). This concern arises from the fact that violence, crimes, terrorism and illicit arms flows are inherently incompatible with SD, particularly SDG 16 – "*Peace, justice, and strong institutions*", which aims to stop these problematic practices (United Nations, 2015, pp. 5-9, 25-26). Fortunately, specialized structures are in place to pre-empt such actions and mitigate unsustainable effects. These measures include raising awareness, establishing stringent legal provisions related to export regulations and control of AM production beyond the purview of national security and defence actors, assessing AM activities through intelligence actions, establishing key AM activity indicators, tracking the sales of AM and digital files, and, last but not least, fostering international cooperation (Stehn et al., 2017, pp. 12-14). Moreover, innovative solutions, such as the "development of an artificial dog-nose device", enable the identification of guns created through AM (Martín Palacios, 2018, p. 37).

All these measures, especially the last one mentioned, are possible through achievements in SDG 17 – "*Partnerships for the goals*". Therefore, the possible unsustainable side of AM could paradoxically foster progress in this respect, bringing public actors into the AM sustainability discussion. However, despite the negative security issues that AM could unveil, the analyzed literature does not take into consideration public actions aimed at enhancing security through the sustainable usage of AM. Moreover, as mentioned before, in the

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case of some SDGs, notably SDGs 16 – "*Peace, justice, and strong institutions"* and 17 – "*Partnerships for the goals"*, AM has not received ample credit for SD. The analysis performed by other authors focused solely on studies within the private sector, making it imperative to explore the potential contribution that the defence domain, a part of the public sector, also responsible for security, could make, given its significant interest in this technology and the potential to diminish its unsustainable effects. Its decisive role comes not only from implementing SDG 16, but also in providing favorable conditions for implementing other SDGs. This perspective is supported by the fact that the military organization was among the first to express interest in parts created through AM (Montero et al., 2020, p. 3), inherently possessing the potential to act as a key player on the sustainability path. The figure below provides a brief illustration of the literature-review process conducted so far (see Figure 1):

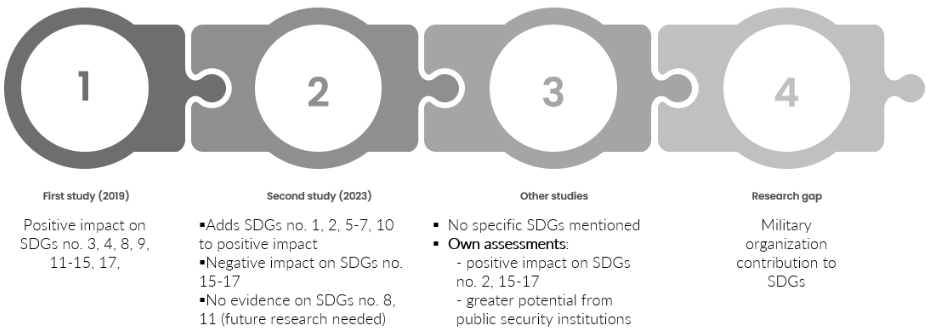

Fig. 1. The literature review on AM contribution to sustainability

The following section presents the case of US military forces, shedding light on the rationale behind the adoption of AM in their pursuit of mission objectives and the preservation of security, revealing an in-depth analysis of the contribution the military could have to specific SDGs and associated targets from AM perspective.

3. Military AM technology usage contributes to SDGs and associated targets. The case of the US military forces

This case study introduces a distinctive AM sustainability approach for two primary reasons. Firstly, the assessment diverges from the conventional evaluation of a private, productive entity, focusing instead on a military organization. Secondly, it aims to explore whether a military entity, which contributes considerably to security and is considered to generate negative spending, as the procurement of combat equipment and systems does not bring added value in society (Azam, 2020), could contribute positively to the implementation of SDGs and associated targets. Consequently, this exploration goes beyond the roles mentioned in the previous section, such as ensuring intelligence and fostering cooperation.

The selection of the US military forces as a case study is driven by the notable interest revealed in the analyzed literature regarding their adoption of AM technology (Fey, 2017, p. 23), a strategy being recently adopted in this respect (Joint Defense Manufacturing Council, 2021), aligning with the historical goal of maintaining technological dominance in military power (Brimley et al., 2013, pp. 9-10). The interest is justified by three critical reasons that position AM as a logistic and operational facilitator: firstly, its contribution to national defence modernization; secondly, its role in improving materiel readiness; and thirdly, its support for tactical innovation, for units deployed in a theatre of operation (Office of the Secretary of Defense, 2018, pp. 5-11). The intent is to use AM primarily in expeditionary missions, for the logistic support of forward deployed and afloat units (Joint Defense Manufacturing Council, 2021, p. 14). Secondly, apart from the mentioned strategy, US DoD issued instructions dedicated to using AM technology by its armed forces, creating the favorable premises for large-scale adoption (Office of the Under Secretary of Defense for Research and Engineering, 2021). Finally, this interest is underpinned by statistical data indicating that the USA leads globally in AM capacity, retaining 33% of the international share - three times more than any other player (Wohlers et al. 2022, p. 7) - with an experience spanning over four decades (Brice, C. *et al*., 2023, p. 16). Consequently, the expectation is that this extensive AM usage will be mirrored in the military domain, yielding valuable insights for this study.

In this context, the case study aims to answer two pivotal research questions:
1) Why are the American military forces interested in AM technology?
This question arises from the distinctive nature of military structures, which, while pursuing the same efficiency goal, differentiate from profit-focused entities as they are not traditionally involved in the production process (Louis et al., 2014, pp. 4-7). Their primary concerns are retaining operational benefits from using military products and seeking operational advantages (Joint Defense Manufacturing Council, 2021, pp. 4-5). However, adopting AM technology could bring military structures closer to productive entities, enhancing their resilience and contributing to sustainability.
2) How do the American military forces contribute to implementing specific SDGs through AM adoption? This question can raise awareness and unveil new measures and possibilities for achieving SD. Examining concrete examples will provide compelling arguments, revealing a distinct and novel contribution that complements existing knowledge. Additionally, the insights from addressing this question may offer valuable lessons to facilitate various military structures' widespread adoption of AM, thereby enhancing their unexpected contribution to SD.

For organizational clarity, this case study will be structured into two subsections, each dedicated to one of the previously formulated research questions.

3.1. Reasons for AM adoption by the US military forces

The comprehensive review of the literature has revealed a myriad of reasons motivating the adoption of AM by the US military forces. The imperative for enhanced efficiency arises from multifaceted needs, particularly in maintenance and supply chain management, both in peacetime and expeditionary operations. Budgetary constraints underscore the need for an effective solution (Louis et al., 2014, p. 2). At the same time, AM is poised to contribute substantially to the digital supply chain (Louis et al., 2014, p. 14), ultimately resulting in a reduced logistic footprint of forces deployed abroad (Brice et al., 2023, p. 21).

From a financial standpoint, AM holds the potential to generate economies of scale, predominantly linked to prolonging the life cycle of military equipment. As an illustrative example, the annual obsolescence costs associated with outdated military systems, estimated at $750 million for the US Navy alone, could be mitigated through AM, as this technology enables the manufacturing of parts that are no longer available on the market, postponing procurement of new military equipment (*Apud* Freeman et al., 2015, p. 6).

Avoiding resource wastage is a primary concern at the force category level, especially when conventional maintenance procedures prove inadequate during austere times (Tadjdeh, 2014, pp. 24-26). The consequential effects are linked to a broad spectrum of economic and operational advantages applicable to all military structures. These advantages include but are not limited to reduced manufacturing and maintenance time (Inspector General, 2019, p. 7), diminished dependence on fuel and transportation assets, mitigated risks associated with dysfunctional supply chains (Louis et al., 2014, p. 4), the ability to customize products following specific requirements (Cotteleer et al., 2014, p. 9), the incorporation of sensors directly printed on weapons or the battle dress uniforms (Louis et al., 2014, p. 10), improved performance of existing or new products (Louis et al.,

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2014, p. 14) and reduced waste (Coykendal et al., 2014, p. 11), to name just a few. Ultimately, this approach not only enhances readiness but also minimizes the overall consumption of resources.

The operational benefits of AM technology were validated during the recently conducted operations of the US military forces in Afghanistan, where the US Army successfully deployed and used AM laboratories to address challenges related to plastic components affected by extreme heat (Cox, 2012). Furthermore, the battlefield utility of AM was rigorously tested during the US forces' participation in the Trident Juncture Exercise held in Norway in 2018. This exercise included securing AM-specific files between coalition forces (Joint Defense Manufacturing Council, 2021, p. 12). Nevertheless, an audit report from 2019, at the US Army level disclosed a temporary use of AM-manufactured parts until the original products became available (Inspector General, 2019, p. 8). This approach, indicative of a high-risk aversion, could be considered a duplication of supply efforts justified by the urgent operational needs. The risk-averse approach is also specific to the US Air Force, which obtains important economies by using AM to produce "noncritical weapon system components" and other accessories (Inspector General, 2019, p. 10).

What is more, the wargaming tactic was applied by the US DoD in conjunction with several contractors and public actors to test the performance of AM integration in the defence procurement area and decide upon a widespread adoption (Mickley, Swank, Hagen, 2021, p. 75). This fact attests to the importance of a comprehensive approach, and the recognized AM benefits deserve a more significant effort for a successful implementation. This measure was implemented to address specific operational challenges, as there was evidence about units that failed to consider all the AM implementation requests and could not use the purchased 3D printers (Mickley, Swank, Hagen, 2021, p. 80). The comprehensive approach is particularly pertinent to joint operations, as the potential of AM technology to confer operational advantages at this level is substantiated by the enhanced self-sustainment and readiness of the units across different Military Services (Office of the Under Secretary of Defense for Research and Engineering, 2021, p. 3).

The examples provided revealed the high AM potential to facilitate three logistic functional areas within the US military forces - supply (with parts and fuel), materiel life-cycle support, and equipment maintenance (NATO Standardization Office, 2018, pp. 5/1-5/4). An assessment of the ten classes of supply specific to US military structures (Joint Chiefs of Staff, 2019, pp. II-5, II-6) revealed that only two are particularly amenable to AM solutions: class II (comprising items of clothing, individual equipment, administrative materials, and tools) and class IX (focused on repair parts) (Muniz, Peters, 2016, p. 47). Nevertheless, the utility of AM technology extends beyond these classes, as evidenced by the acceptance of 3D printed elements in military food rations (Caulier et al., 2020, p. 10), augmenting AM's contribution to the supply chain and for obtaining blood vessels and skin (Fey, 2017, p. 25), critical for another logistic functional area: medical support (NATO Standardization Office, 2018, p. 5/5).

In 2023 fiscal year, the interest in AM was closely tied to its application in building and repairing ships as a solution to address the high costs generated by these operations. Additionally, there was a concerted effort to establish the state of AM process qualification and certification for aerospace vehicles, along with addressing associated barriers (House of Representatives, 2022, pp. 14, 217-218). The recent AM applications developed by the US DoD include constructing a runway for the air force (Clemens, 2022), manufacturing submarine parts (Avery, 2023), and producing dental prosthetics for on-board military sailors (Clemens, 2022).

Excepting the operational (logistical) benefits, the most crucial reason for the keen interest of the US DoD in integrating AM technology lies in its potential to steer the defence industrial capability of this country, which enables a resilient and functional AM supply chain, as the availability of products and services connected to this capability is also a significant concern (Office of the Under Secretary of Defense for Research and Engineering, 2021, p. 3). Thus, the fourth line of logistic support, which includes industrial capabilities and serves as a source

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for the other three lines of logistic support (NATO Standardization Office, 2018, p. 1/8), is being made functional. This approach not only enhances the military's operational efficiency but also strengthens the nation's overall defence industrial capacity.

The reasons for the adoption of AM by the US military forces, as outlined thus far, have primarily centered around utilizing AM solutions for small-scale manufacturing to provide on-the-spot logistic support to military forces. However, there is a current intent to extend the application of AM solutions to a larger scale (House of Representatives, 2022, p. 61). Recognizing the vast potential of this technology to address broader logistic needs, the authorities of Guam, an island within the USA territory, have initiated a comprehensive study. This aims to analyze the possibilities of the island for large-scale manufacturing using AM technology, with the US DoD and its Allies as initial customers (Brice et al., 2023, p. 1). In this particular case, the main reason US military forces are looking to leverage AM technology on a larger scale is intricately tied to the strategic interest of the USA in the region, and particularly to the security and supply chain advantages offered to all national and allied Military Services (Kan, 2014, pp. 2-12). Thus, the economic development and security needs are addressed comprehensively, opening new opportunities for advancements in SD and technological superiority.

The upcoming subsection will further build on this framework, linking small-scale and large-scale AM adoption by the US DoD to operational interests, specific SDG targets, and a comprehensive overview of the potential contribution this military organization could make to security and sustainability.

3.2. The potential contribution of the US military forces to Sustainable Development Goals and targets through AM adoption

As presented in the previous subsection, the reasons for adopting AM technology by the US Military Forces share commonalities with sustainability arguments depicted from the analyzed literature in *Section 2*. This sub-section provides an in-depth analysis of the US military forces' potential contribution to the implementation of SDGs resulting from the adoption of AM technology on both small and large scales.

In the context of AM adoption by the US DoD on a small scale, the interest comes from internal needs that hold the potential to contribute to the economic and social dimensions of SD. Firstly, the possibility of reducing maintenance costs for military equipment aligns with SDG *target 1.1*, centered on economic poverty reduction (United Nations, 2015, p. 15), with cheaper raw materials and AM parts being significant drivers of this technology (Office of the Secretary of Defense, 2018, p. 11). Notably, the analyzed literature did not reveal instances where AM, as a military logistic solution, generated higher costs; on the contrary, the possibility of avoiding procurement of entire military equipment or having low costs for small quantities stands as a robust economic argument for AM adoption (Inspector General, 2019, p. 6). Additionally, this idea can be sustained by the shorter period when the equipment is back on the battlefield, cancelling the need for procurement (Inspector General, 2019, p. 7). This contributes to a lower level of military spending, affording authorities to allocate funds towards other military or civilian needs, thereby alleviating economic burdens and advancing towards poverty eradication or other security concerns.

Secondly, there are prospects of a clear contribution to SDG *target 2.1* which focuses on providing access to food for *"people in vulnerable situations"* (United Nations, 2015, p. 15), like soldiers deployed in isolated, rough terrain, experiments with 3D printing of food rations being conducted (*Apud* Fey, 2017, p. 25). Thirdly, the fact that the US experiments also pursued the 3D printing of skin and blood vessels in order to save wounded soldiers on the battlefield, represents a noteworthy advancement in military medicine, which could complement the civilian medicine efforts in AM related medical applications, contributing thus to *SDG target 3.8* (United Nations, 2015, p. 16). As for the concerns expressed by other authors concerning the negative impact AM could have on their users' health (Machado et al., 2019), it is noteworthy that the US DoD structures solved this problem through

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a face shield, which effectively prevents the entry of toxic particles into the respiratory system (Braunberger, 2020, p. 31).

However, at small-scale adoption, the sustainability impact is difficult to assess for several reasons: different situations, different AM procedures, different raw materials and low quantities (which are typically more expensive), coupled with the lack of a robust procedure to register, monitor and report the spending generated by AM solutions. Nevertheless, the US DoD is actively addressing these challenges through audit missions, highlighting the need for improved tracking of AM spending (Inspector General, 2019, p. 5). This initiative will empower the US military decision-makers to choose the most sustainable option, provided operational and sustainability criteria are considered.

Additionally, when military interests align with economic objectives, leveraging the dual-use capability that AM offers from this perspective, the SD benefits could be higher. This synergy is exemplified by the Guam project, where the intention to integrate AM at a large scale is expected to not only address economic and social dimensions associated with military internal needs but also contribute to the environmental dimension of SD. From this perspective, the Guam project is a rare example of a comprehensive approach, delivering sustainable benefits for the military and the local community.

In this respect, one intention is to contribute to local tourism development through the expected enhanced maintenance capacity for military and civilian aircrafts, submarines and vehicles (Brice et al., 2023, pp. 24, 26, 52). Firstly, the unusual combination of military interests and tourism could have a consistent contribution to SD of the area, but mainly to *SDG target 8.9*, promoting sustainable tourism measures that generate new jobs and support local products and culture (United Nations, 2015, p. 20), solving the economic downturn caused by the COVID-19 pandemic (Brice et al., 2023, pp. 14, 27, 104). Secondly, the project aligns with sustainable industrialization actions, addressing SDG *target 9.2* (United Nations, 2015, p. 20). This involves leveraging technological innovations associated with AM adoption, contributing to the growth and sustainability of local industries.
Thirdly, the construction domain in Guam will also benefit from the military presence. This encompasses addressing deficits in specific jobs and overcoming challenges related to the availability of construction materials. This aligns with *SDG target 11.c*, focused on sustainable buildings created from local materials (United Nations, 2015, p. 22) and apply the advancements obtained by US marine and land forces in 3D concrete printing (Brice et al., 2023, p. 31).

Fourthly, beyond the direct benefits brought to the military and tourism sectors, which currently dominate the occupational landscape in Guam, the strategic project is expected to bring economic diversification. This will be supported by AM technological innovation and financial support to local businesses (Brice et al., 2023, p. 34), contributing directly to *SDG targets 8.2.* and *8.3* and tangentially influencing *SDG target 9.b.* (United Nations, 2015, pp. 19-20)

Regarding *SDG target 1.5*, oriented towards disaster relief (United Nations, 2015, p. 15), it can be acknowledged that AM adoption by the US DoD could have a contribution in this respect, enhancing the availability of materials and equipment needed by the US military forces to address disaster and humanitarian needs in the area (Kan, 2014, pp. 1, 8). This approach facilitates quicker responses without positioning preventive stocks or resupply transportation, yielding economic and social benefits. This capacity enhances the ability of the region to face natural calamities, aligning with *SDG target 13.1* (United Nations, 2015, p. 23).

Another sustainable aspect that needs to be considered is that the strategic project developed by the US DoD in Guam depends on sustainable sources of financing (Brice et al., 2023, p. 75). This approach strengthens local financial institutions, thus contributing to *SDG target 8.10* (United Nations, 2015, p. 20) and facilitating the development of other local businesses, already mentioned to align with *SDG target 8.3*. The DoD will also support these new businesses, which is expected to invest "more than $11 billion in Guam" (Brice et al., 2023, p. 78).

The social dimension of sustainability is also favored by the widespread adoption of AM by the US DoD. In the context of the Guam project, where local manufacturing is not sufficiently developed, the anticipated AM site to be established by the US military promises to enhance production capacity. This could utilize locally sourced materials, providing locals with access to sustainable, better-paid jobs, not only in the military and tourism domains but also in other sectors like construction (affordable 3D printed houses and military barracks), agriculture, space/satellite, etc., where AM can bring benefits (Brice et al., 2023, pp. 31, 34, 38, 67). The integration of AM into agriculture aligns with SDG *target 2.a*, which seeks agricultural advancements through technology (United Nations, 2015, p. 16). Moreover, this initiative has the potential to contribute to *SDG target 11.1*, and *SDG target 11.c,* which point to the need for accessible living spaces constructed from locally available raw materials (United Nations, 2015, pp. 21-22).

As the Guam project is not feasible with the actual workforce, there is a significant need to orderly integrate migrants (Brice et al., 2023, pp. 38, 53), fact that will generate a contribution to *SDG target 10.7,* which supports migration policies (United Nations, 2015, p. 21). However, security concerns have imposed strict conditions based on migrants' nationality, the ones from China not being accepted several years ago (Kan, 2014, p. 15).

As the innovative AM technology requires a highly skilled workforce, there has been established a need for new academic and skill development programs, to adapt to AM challenges and to make the project feasible, as only a plan can become reality with a well-prepared human resource. From this perspective, measures like establishing precisely the required professions and their unique skill sets (also for defence manufacturing sub-domain), assessing the capacity and educational portfolio of existing educational institutions, differentiating between skills that can be acquired through online versus on-site classes, informing future workers and students and raising awareness about the benefits of these occupations (Brice et al., 2023, pp. 39-49), are examples of an efficient approach. At the same time, the aforementioned measures could generate contributions to *SDG targets 4.3, 4.4 and 4.5,* which have in common the request to provide relevant technical skills and knowledge to meet the evolving needs of society (United Nations, 2015, p. 17). As research and educational facilities on the island focused on teaching people how to make the best use of recycled materials, it is expected that AM integration for both military and civilian purposes to serve local community, through contribution to a healthier environment (Brice et al., 2023, p. 47). In this context of educational shift and adaptation, the incentives are represented by higher than the national rate incomes (Brice et al., 2023, pp. 38, 53), fact that contributes to the feasibility of the project and, at the same time, to SDG *target 10.1* (United Nations, 2015, p. 21).

Another important facet of the contribution the Guam military AM project has made to the social dimension of sustainability lies in its significant potential to promote inclusion. Researchers underscore the necessity to consider the entire workforce available on the island, based on a good understanding of diversity and equity issues. This measure holds promise in maximizing the available resources, especially considering the higher number of female students compared to male students, a lower percentage being met in college (Brice et al., 2023, pp. 49-51). This focus on young students in general, and on women, in particular, could also bring benefits to SDGs *targets 10.2* and *13.b* (United Nations, 2015, pp. 21-23), raising the capacity to implement the project successfully.

Moreover, the environmental dimension of sustainability reaps significant benefits from the US military investment in AM, particularly considering the streamlining of supply chain processes. Establishing local production capabilities in Guam could transform the island into a "transshipment hub", cancelling the need for extensive transportation, fuel and specific assets, thereby reducing emissions associated with American and Asian markets (Brice et al., 2023, p. 26). Despite these advancements, there will still be ongoing resupply requirements, particularly for consumable hardware and raw materials, which must be brought from the original supplier or unavailable on the island (Brice et al., 2023, pp. 64-67). However, even with these considerations, there is a notable reduction in pollution of the marine environment, offering inputs for *SDG target 14.1*; if the interest in tourism revitalization on a small island like Guam is considered, there could also be a contribution to *SDG target 14.7* (United Nations, 2015, pp. 23-24). Additionally, the considerable waste reduction brings benefits to the environment. However, the lower volume of waste still needs to be managed properly, to avoid environmental and health problems, regulatory requirements are necessary (Brice et al., 2023, p. 62). In this respect, prioritizing recycling emerges as a crucial goal, bringing benefits related to lower levels of raw materials and energy consumption, thereby supporting *SDGs targets 1.1* and *12.5* (United Nations, 2015, pp. 15, 22).

As Guam explores the development of alternative energy sources through the utilization of AM, the prospect of locally producing parts for the generating equipment (Brice et al., 2023, p. 91) brings the zero-emission goal closer to reality, while the energy clean profile of the island can be obtained by exceeding the 25% level of 2021, a variety of alternative power sources being taken into account (solar, hydro, and even wind sources) (DeRivi, 2021). Because the AM technology has the potential to boost the availability of specific and cheaper clean energy equipment (Brice et al., 2023, p. 91), *SDG targets 7.a* and *7.b*, which focus on sustainable, clean energy sources and services, could be supported and also supporting *SDG target 7.3*, which calls for the need to double the energy efficiency (United Nations, 2015, p. 19). This comprehensive plan, coupled with a commitment to circular economy practices, corresponds to *SDG target 12.5*, which pursues measures of preventing, reducing, recycling and reusing waste materials (United Nations, 2015, p. 22), AM technology having an important role in these endeavors. These actions could also potentially impact the availability of unpolluted water sources and spare parts for corresponding systems. The very fact that Guam Power and Guam Waterworks are part in the project (Brice et al., 2023, pp. 90-91) represents a clear signal that energy and water challenges are being addressed seriously, aligning with SDG *targets 6.1* and *6.3* (United Nations, 2015, p. 18).

What is more, the US DoD underscores its commitment to steering a circular economy through the sustainable potential of AM in the Guam project, while affecting the fossil-fuel-based energy sources through manufacturing easy recyclable products (Brice et al., 2023, p. 36). In contrast to earlier military papers that predominantly highlighted operational advantages with minimal emphasis on environmental impact, the Guam project represents a distinctive approach. Here, the adoption of AM technology for military applications is intricately linked with "*green workflows*", emphasizing the most efficient resource allocation and the least environmental impact (Brice et al., 2023, p. 36). At the same time, the Guam project marks a shift towards manufacturing easily recyclable products, impacting fossil-fuel-based energy sources, aligning with the broader goal of promoting sustainability and minimizing the ecological footprint. By intertwining AM technology with environmentally conscious practices, the project sets a precedent for how military initiatives can actively contribute to circular economy principles, fostering resource efficiency and environmental stewardship. The holistic approach reflects an evolving mindset within the military, acknowledging the importance of operational effectiveness and environmental responsibility in the pursuit of long-term sustainability.

Another way the US military structures contribute to SD is their commitment to cooperation and partnerships, aligning with the principles of SDG 17 – *Partnerships for the goals*. For the US DoD, the interest in AM, cooperation and partnerships exceeds the limits of the national military structures, AM challenges being addressed together with government, industrial base, academic and NATO partners representatives (Joint Defense Manufacturing Council, 2021, pp. 10-11). To highlight the impressive "network" developed by US DoD around AM effort, there can be mentioned: eight public-private partnerships, National Aeronautics and Space Agency (NASA), Department of Energy (DoE), Federal Aviation Administration (FAA), Manufacturing Innovation Institutes, and the Department of Commerce (DoC) (Joint Defense Manufacturing Council, 2021, p. 11). These key stakeholders play pivotal roles in facilitating the successful implementation of AM for military needs.

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Coordinated by America Makes, a national structure with consistent financial support (*Apud* Nelson, 2020, p. 30), these partnerships are critical not only at the national level, but also for effective collaboration with the local community in Guam (Brice et al., 2023, p. 52). Thus, the AM implementation goal in Guam can contribute to both *SDG targets 17.16* and *17.17* (United Nations, 2015, p. 27). An early advantage of these collaborations is evident in the DoE's assessment, which estimated a remarkable 90% reduction in raw and waste materials quantity and a 50% reduction in energy consumption compared to traditional manufacturing methods (Brice et al., 2023, p. 21). These numbers reflect the possibility of the US DoD to contribute to SD through AM adoption in military sites like the one in Guam, and more specifically to SDG *target 1.1*., a reduction in the manufacturing resources being translated into their higher availability for future generations.

As a whole, the Guam militarization project serves as a noteworthy model of sustainable industrialization, the US DoD and the other involved actors contributing significantly to the implementation of *SDG target 9.2*, which follows this effect (United Nations, 2015, p. 20), as depicted from the previous examples. What is more, as the critical elements needed to make this project effective and efficient can be provided by the US DoD (AM software, equipment, feedstock, part manipulation and validation), this military actor is seen as the "ideal partner" (Brice et al., 2023, pp. 1, 94).

Apart from the presented SD potential contribution that the US DoD and its Military Services can have by fostering the broader implementation of AM technology, it is not advisable to minimize the role of the military structures, in general, to SD, as the favorable context for development is only possible due to a peaceful environment (United Nations, 2015, p. 9). Thus, defensive military forces retain the noble mission to support peace, creating the premises for SD advancements while also contributing to *SDG target 16.1*, which is focused on reducing "all forms of violence" (United Nations, 2015, p. 25). Consequently, the military lens provides AM sustainability debate with a second positive vision, apart from the general perception that considers it unsustainable. It is the case of Guam militarization project, assessed to bring additional security in the area.

The following table summarizes the main findings in this article, related to the contribution of the US DoD military structures to the implementation of SDGs and their associated targets (Table 1):

Table 1. The list with military Guam project contribution to Sustainable Development

SDG*	Target*	Effects generated by US DoD military structures' adoption of AM
SDG 1: *No poverty*	1.1. Poverty reduction	• reduced maintenance costs for military equipment • cheaper raw materials and AM parts • postponed procurement of the entire military equipment • audit on the level of AM spending • development of local economy • dual-use manufacturing capability • cheap buildings from 3D printed concrete • lower needs for raw materials through recycling • reduction in the amount of energy, raw and waste materials
	1.5. Disaster relief	• availability of materials and equipment needed by US military forces in disaster relief missions
SDG 2: *Zero hunger*	2.1. Access to "safe, nutritious and sufficient food [...]"	• 3D printed military food rations for soldiers in difficult missions
	2.a. "[...] technology development [...] to enhance agricultural productive capacity"	• Stimulating agriculture through AM implementation
SDG 3: Good health and wellbeing	3.8. "access to quality essential health-care"	• 3D printed prosthetics for soldiers in difficult missions • 3D printed skin and blood vessels for wounded soldiers • adequate protective equipment for AM workers

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SDG*	Target*	Effects generated by US DoD military structures' adoption of AM
SDG 4: Quality education	4.a. "[...] inclusive and effective learning environments for all"	• establishing the required professions and their corresponding skills • assessing the capacity and educational portfolio of the existing educational institutions • differentiating between skills that can be acquired through online vs. on-site classes • informing future workers and students • raising awareness about the benefits of AM occupations
	4.5. "equal access to all levels of education [...] for the vulnerable, including persons with disabilities"	• women have access to education and are not excluded from AM development plan
	4.4 "increase the number of youth and adults who have relevant skills, including technical [...] skills"	• taking into consideration students, including female students, for AM jobs
	4.5 "[...] eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable [...]"	• youth and migrants (including women) taken into account for AM development plan
SDG 5: Gender equality	5.1. closing the gender gap	• female students have access in AM development activities
SDG 6: Clean water and sanitation	6.1. "[...] access to safe and affordable drinking water for all [...]"	• participation of energy and water responsible structures in workshops focused on AM implementation
	6.3 "improve water quality by reducing pollution and [...] substantially increasing recycling"	• participation of energy and water responsible structures in workshops focused on AM implementation • recycling taken into account, with benefits for water quality
SDG 7: Clean and affordable energy	7.3 Enhanced energy efficiency	• boosting the availability of specific and cheaper clean energy equipment
	7.a "[...] investment in energy infrastructure and clean energy technology"	• boosting the availability of specific and cheaper clean energy equipment • clean energy equipment and the specific parts enhanced availability through AM
	7.b "[...] expand infrastructure and upgrade technology for supplying modern and sustainable energy services [...]"	• boosting the availability of specific and cheaper clean energy equipment
SDG 8: Decent work and economic growth	8.2 "[...] economic productivity through diversification, technological upgrading and innovation [...]"	• economic diversification generated by AM
	8.3 financial support for companies	• financial support to local businesses (DoD contribution included)
SDG 8: Decent work and economic growth	8.9 "[...] sustainable tourism [...]"	• sustainable tourism through access to specific jobs and local products promotion
	8.10 Access to financial support	• strengthen the local financial institutions
SDG 9: Industry, innovation, and infrastructure	9.2. "promote inclusive and sustainable industrialization [...]"	• sustainable industrialization: dispersion of manufacturing sites, job creation for youth, women and migrants • AM software, equipment, feedstock, part manipulation and validation provided by US military
	9.b "Support domestic technology development [...]"	• economic development supported by AM technologic innovation

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SDG*	Target*	Effects generated by US DoD military structures' adoption of AM
SDG 10: Reduced inequalities	10.1. "[...] sustain income growth [...] at a rate higher than the national average"	• AM jobs may generate higher than the national rate incomes
	10.2. "[...] social, economic and political inclusion of all [...]"	• AM job creation for youth, women and migrants
	10.7 Migration policies	• integration of migrants into the workforce, with security concerns mitigated
SDG 11: Sustainable cities and communities	11. 1 "[...] access for all to adequate, safe and affordable housing [...]"	• affordable places for living (3D printed houses and military barracks)
	11. c "[...] financial and technical assistance, in building sustainable and resilient buildings utilizing local materials"	• cheap buildings from localized materials (3D printed concrete)
SDG 12: Responsible consumption and production	12.5. "[...] reduce waste generation through prevention, reduction, recycling and reuse"	• fostering circular economy • recycling of waste • lower level of energy consumption • alternative power generating equipment with parts created locally • energy clean profile of the island
SDG 13: Climate action	13.1. "[...] resilience and adaptive capacity to climate-related hazards and disasters [...]"	• availability of materials and equipment needed by US military forces to intervene for disaster relief
	13.2. climate change policies	• the circular economy approach • decarbonization through reduction in the amount of energy, raw and waste materials • pollution reduction measures • support for clean energy production
SDG 14: Life below water	14.1. "[...] reduce marine pollution [...]"	• reduced level of pollution in the marine environment (reduced level of transportation, fuel, etc. and polluting emissions)
	14.7. economic benefits through sustainable tourism	• tourism revitalization AM potential
SDG 16: Peace, justice, and strong institutions	16.1 Reduced violence and death levels	• AM in support of defensive military forces • security concerns at the base of AM development
SDG 17: Partnerships for the goals	17.16 Global partnerships	• AM challenges addressed with government, industrial base, academic and NATO partners representatives • US DoD seen as an "ideal partner"
	17.17 "[...] effective public, public-private and civil society partnerships [...]"	• AM challenges addressed with government, industrial base, academic and NATO partners representatives

Source: created by authors, on the basis of the analyzed case
* SDGs and targets description from: United Nations, *Transforming our world: the 2030 Agenda for Sustainable Development*, New York, 2015, pp. 14-27, and https://sdgs.un.org/goals

However, while the economic, social and environmental benefits are evident from AM technology development perspective, the environmental impact of the military activities in the area represent a real concern, raising concerns regarding landholdings and military interference in local authorities' decisions, that could hamper the natural environment protection (Brice et al., 2023, p. 52). From this perspective, it can be argued that the AM military implementation project in Guam may not be entirely sustainable. This assessment has all rights to be valid, as the military project contributes to the implementation of 34 SDG targets presented in the table above, out

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of the 169 targets formulated by the United Nations (United Nations, 2015, pp. 13-27), a share of almost 20%. Therefore, it should be taken as a good start for a military organization, as the difficulty of accomplishing the complex mission of SD is widely known. Additionally, there could be voices expressing the rival explanation that the US DoD pursues sustainable initiatives in the area only because the military presence in Guam was accepted on the condition to bring benefits for the local population (Kan, 2014, p. 17). Nevertheless, the examples provided in this sub-section show a genuine concern for the development of the local community, as a unique solution to make AM project feasible, as the military cannot adopt AM at a large scale only through internal resources. Therefore, it is a win-win situation in which both military and civilian partners retain sustainable benefits.

4. Summary and conclusions

This article presented a unique private-public approach in assessing the contribution of AM technology on the sustainability path. From the private assessment side, conducted in the section dedicated to literature review, it can be concluded that certain new AM applications, such as those alleviating pressure on land resources or utilizing microrobots, paint a positive picture about the contribution of this technology to SDG 15, contradicting previous findings. Similarly, positive effects on SDGs 16 and 17 are noted, shedding light on a potentially more significant contribution that AM adoption could make to SD.

Additionally, recognizing the crucial role of public security institutions in implementing the last two SDGs, this study delved deeper into this issue, presenting a novel perspective that has not been thoroughly explored previously: the contribution of military organization to SD, through AM small and large-scale adoption. The case study performed to explore this perspective provided valuable answers to both research questions. Concerning the first question, the high level of interest displayed by the American military forces in adopting AM is mainly supported by the need to mitigate financial and supply chain problems and avoid resource wastage. Consequently, military logistics has the chance to become more supple and efficient, contributing thus to important operational advantages. Overall, the benefit of adopting AM to a small scale on the battlefield transforms it into a major military logistic driver, which can develop the country's defence industry. The US military decision-makers are oriented towards a large-scale adoption of AM to make this happen and gain a strategic foothold in certain areas.

As a result, while the small-scale adoption of AM solutions in the military organization are not to be neglected, from the large-scale adoption perspective, particularly exemplified by the Guam project, it can be concluded that this technology has, indeed, a greater potential, conferring the military organization an active and positive role to SD. Thus, with regard to the second question, this study revealed the possibility that AM contributes positively to all SDGs, albeit partially, with only one-fifth of the SDG targets favored. It also emphasizes the need for further research, particularly in areas like SDGs 8 and 11, where additional investigation can uncover more insights and refine the knowledge related to the sustainability of AM technology.

Therefore, another important aspect revealed by this study is the need to look deeper into the contribution of AM adoption to SDGs. By adopting the framework of the 169 SD targets, this study broke down the complex landscape of sustainability. Unlike a general approach that might be misleading, the study revealed that AM military projects could contribute to all SDGs (100%), but only to 34 out of the 169 SD targets, resulting in a more realistic impact of only 20%.

Despite this relatively low percentage, the military interest in AM integration is deemed significant both for sustainability and security reasons. This aspect is supported by the list developed in this study, which serves as a valuable reference for both private and public actors involved in large-scale AM adoption, which also pursue sustainability targets. Further research is needed to explore the potential contributions of other public actors, like military and civilian structures from other nations. To provide a more detailed assessment, access to quantitative data would be essential to reach a conclusion with respect to AM contribution to sustainability.

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