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DEPARTAMENTO DE ESTUDOS PÓS-GRADUADOS  
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**DEVELOPMENT OF AN N-HELIX INNOVATION MODEL FOR THE  
PORTUGUESE DEFENSE INDUSTRY**

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SEU AUTOR, NÃO CONSTITUINDO ASSIM DOCTRINA OFICIAL DAS  
FORÇAS ARMADAS PORTUGUESAS OU DA GUARDA NACIONAL  
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MAJOR, INFANTARIA**





**INSTITUTO UNIVERSITÁRIO MILITAR  
DEPARTAMENTO DE ESTUDOS PÓS-GRADUADOS**

**DEVELOPMENT OF AN N-HELIX INNOVATION MODEL FOR  
THE PORTUGUESE DEFENSE INDUSTRY**

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**Tese de Doutoramento em Ciências Militares**

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Pedrouços, 2023





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## **Abstract**

This doctoral thesis in military sciences comprises a compilation of original research papers that make substantial contributions to the body of knowledge within the defense industry. These findings merit both national and international recognition, underscoring their significance through publication in scientific journals. The thesis adopts a distinctive format, presenting a cohesive compilation of three previously published empirical articles along with two supporting ones. The primary objective of this thesis is to delve into a comprehensive understanding of real-world phenomena, particularly examining the dynamics among industry, universities, and the State, as viewed through the lens of the quintuple helix innovation model (Carayannis & Campbell, 2010). Simultaneously, it aims to describe and critically assess novel and complex opportunities for the defense industry's engagement, with a focus on N-helix innovation models. Grounded in the social and military sciences, this research predominantly employs qualitative methodologies, primarily relying on case studies and various data sources such as semi-structured interviews, direct observations, and official documentation. Preliminary research findings have shown that the defense industry is gaining new momentum, as emerging technologies are enabling highly innovative and disruptive systems. This thesis addresses fundamental questions concerning the allocation of limited financial resources to foster high-tech defense industries. In this context, it is crucial to attain a nuanced understanding, analysis, and description of emerging N-helix innovation models. The core aspiration of this study is to streamline the relationship between the armed forces, the defense industry, and military universities, with a strategic focus on the efficient use and advancement of disruptive military technologies.

**Keywords:** Military Sciences; Armed Forces; Defense Industry; N-Helix; Military Universities.

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## **Resumo**

*Esta tese de doutoramento em ciências militares tem por base um conjunto de trabalhos de investigação originais que contribuem para o conhecimento no âmbito da indústria de defesa e que tem merecido divulgação nacional e internacional por via da publicação científica. Assim, a tese de doutoramento seguiu o formato de compilação de um conjunto coerente de três artigos empíricos publicados e dois de apoio, também publicados. O objetivo subjacente à tese está relacionado com a capacidade de compreender um determinado fenómeno da vida real, ou seja, compreender o “como” é efetuado o relacionamento entre a indústria, as universidades e o Estado à luz do modelo de inovação de hélice quádrupla (Carayannis & Campbell, 2010); e, simultaneamente, descrever e analisar criticamente novas e complexas oportunidades de relacionamento da indústria de defesa à luz de modelos de inovação n-hélice; Orientado pelas ciências militares, a investigação segue uma metodologia tendencialmente qualitativa, que utiliza maioritariamente estudos de caso e várias fontes de recolha de dados, tais como, a utilização de entrevistas semiestruturadas, observação direta e documentação oficial. Os resultados preliminares evidenciaram que atualmente a indústria de defesa está a ganhar um novo impulso à medida que novas tecnologias estão a permitir sistemas altamente inovadores e disruptivos. Esta tese responde a questões sobre onde e como investir recursos financeiros limitados para impulsionar indústrias de defesa de alta tecnologia. Nesse sentido, é necessário compreender, analisar e descrever novos modelos de inovação N-hélices. O estado final da investigação teve como objetivo agilizar a relação entre as forças armadas, indústria de defesa e as universidades civis/militares, com vista ao eficiente uso e desenvolvimento de tecnologias militares disruptivas.*

**Palavras-chave:** *Ciências Militares; Forças Armadas; Indústria de Defesa; Inovação; N-Hélice; Universidades Militares.*

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## List of initials and acronyms

### A

A&D	Aerospace and Defense
AAV	Amphibious Assault Vehicle
ACU	Advanced Combat Uniform
AIFV	Armoured Infantry Fighting Vehicle
AuxDefence	Advanced Materials for Defence

### B

BDU	Battle Dress Uniform
-----	----------------------

### C

C-IED	Counter Improved Explosive Devices
CAQDAS	Computer-assisted (or aided) qualitative data analysis software
CARD	Coordinated Annual Review on Defense
CASP	Critical Appraisal Skills Programme
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosives
CDP	Capability Development Plan
CE	Circular Economy
CISED	Research Center in Digital Services
CITEVE	Technological Center for Textile and Clothing Industries
CPLP	Community of Portuguese Speaking Countries
CSDP	Common Security and Defense Policy

### D

D3	Demilitarization, Dismantling and Alienation
DARPA	United States Defense Advanced Research Projects Agency
DG DEFIS	Directorate-General for Defense Industry and Space
DGNDR	Directorate-General for National Defense Resources
DM-DRCP	Deployable Military Disaster Relief Capability Package
DSIA	Defense and Security Industry Association
DTIB	Defense Technological, Industrial Base

### E

EADS	European Aeronautic Defense and Space Company
EC	European Commission

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EDA	European Defense Agency
EDAP	European Defense Action Plan
EDF	European Defense Funds
EDTIB	European Defense, Technological and Industrial Base
EEAS	European External Action Service
EGA	European Green Agreement
EU	European Union
EUMC	EU Military Committee
EUMS	European Union Military Staff
<b>G</b>	
GCS	Ground Control Station
GDP	Gross Domestic Product
<b>I</b>	
I&DT	Innovation and Technological Development
IAEA	International Atomic Energy Agency
IAEA	International Atomic Energy Agency
ID	Identification
IF CEED	Incubating Forum for the Circular Economy in European Defense
IoT	Internet of Things
IUM	Instituto Universitário Militar
<b>K</b>	
KPU	Clothing and Personnel Equipment
<b>L</b>	
LAV	Light Armoured Vehicle
LoA	Level of Ambition
<b>M</b>	
MDN	Ministry of National Defense
MDPI	Multidisciplinary Digital Publishing Institute
MoD	Ministry of Defense
<b>N</b>	
NATO	North Atlantic Treaty Organization
NIS	National Innovation Systems
NSPA	NATO Support and Procurement Agency



**O**

OI Open Innovation

**P**

PESCO Permanent Structured Cooperation

PLA People's Liberation Army

PRISMA Preferred Reporting Items Systematic Reviews and Meta-Analyses

**Q**

QH Quintuple Helix

**R**

R&D Research and Development

R&D&I Research, Development, and Innovation

R&DT Innovation and Technological Development

R0 Refuse

R1 Rethink

R2 Reduce

R3 Reuse

R4 Repair

R5 Refurbish

R6 Remanufacture

R7 Repurpose

R8 Recycle

R9 Recover

RQ Research Question

RSTA Reconnaissance, Surveillance and Target Acquisition

RTD Research and Technological Development

**S**

SCS South China Sea

SCS Soldier's Combat System

SJR Scimago Journal & Country Rank

SLR Systematic Literature Review

SM Supplementary Materials

SME Small and Medium-size Enterprises

Synth Rep Synthesis Report



**T**

T&C Textile and Clothing

TH Triple Helix

Title-Abs-Key Title-Abstract-Keywords

**U**

UAS Unmanned Aerial System

UAV Unmanned Aerial Vehicle

UBI University Business Incubator

UGS Integrated Unmanned Ground System

UGV Unmanned Ground Vehicles

UIG University-Industry-Government

UK United Kingdom

UN United Nations

USA United States of America

U.S. United States

UUV Unmanned Underwater Vehicles



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## 1. Chapter I – Thesis' General Framework

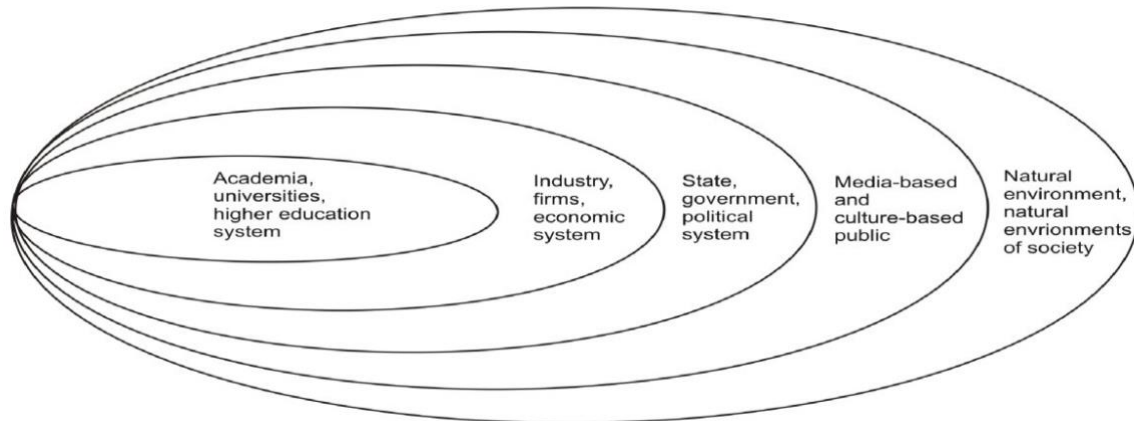
### 1.1. Introduction

This thesis explores "how" the Portuguese defense industry manages its relationships among industry, universities, and the state within the framework of the quintuple helix innovation model. In doing so, it sheds light on unique and complex aspects within the defense industry, contributing new insights to the field of military sciences.

To the best of our knowledge, this research represents a pioneering endeavor in its field. While analogous studies within the quintuple helix framework have been conducted in the private sector, where business models are competitive, the defense industry's innovative nature justifies its inclusion within an n-helix context. The helix models are built on the premise that innovation, gaining increasing importance in evolving ecosystems centered around knowledge, exerts significant influence in shaping societies. The first helix typically embodies academia (and historically, the church) and the educational subsystem, serving as the primary wellspring of knowledge production, including institutions like universities and research centers (König *et al.*, 2021). Additionally, König *et al.*, (2021) argue that the second helix encompasses industry, commerce, and market entities within the economic subsystem. The interconnection of the educational and economic subsystems during the Industrial Revolution gave rise to the notion of a double helix of knowledge production. However, the widespread adoption of the (double) helix concept gained prominence during the 1920s as a lateral cooperation. Silicon Valley's early success was underpinned by a network of university-industry and industry-government double helices. Over time, it evolved into a triple helix structure (Etzkowitz & Zhou, 2017), very similar to what we know today as the university-industry-state paradigm. While the future of military innovation will increasingly be grounded in the domain of the quintuple helix (Figure 1), the enduring relationship among academia, industry, and the state is poised to shift towards a greater focus on technology and environmental considerations.



Figure 1 – Quintuple-helix model and its subsystems



Source: Carayannis *et al.* (2012)

Considering the above, universities serve as instrumental conduits for the transfer of technology to the industry. As a result, these institutions often leverage such contributions to develop prototypes and introduce cutting-edge military technologies, with the goal of their deployment by the armed forces. Furthermore, the quintuple helix paradigm envisions not only the advancement of domestic military capabilities but also the marketing of innovative military products to foreign military markets and private companies—a concept commonly known as "dual use". Lastly, the quintuple helix framework emphasizes ecological preservation and concerns for ecosystems and the global environment. While the ecological argument is somewhat criticized, it finds support in the perception that environmental damage during wartime is often deemed an unfortunate yet unavoidable aspect of collateral damage (Marler, 2013). Conversely, civil society exhibits a reluctance to tolerate the environmental repercussions stemming from military operations (Marler & Moore, 2011). Consequently, promoting the ecologically responsible conduct of warfare is both a scientific imperative and a moral duty (Machlis & Hanson, 2011). Hence, there arises a pressing need to mitigate the profound destructive consequences of war and curtail the degradation of ecosystems and human lives.

In brief, the quintuple helix concept aspires to establish a symbiotic relationship encompassing university, industry, the state (military), technology, and the natural environment. Anticipated as catalysts within the defense industry, N-models are poised to strengthen the collaboration among the armed forces, the defense industry, civilian/military universities, social capital, and the natural environment. This synergy is directed toward effectively utilizing and advancing military equipment and technologies. Thus, it becomes



necessary to comprehend, analyze, and delineate the potential of N-helix innovation models, in addition to the well-established quintuple innovation model.

Concerning technology, a central theme addressed in this thesis, we adhere to the principles outlined by Grübler (2003), occasionally in alignment with the various forms of intelligence as proposed by Huang and Rust (2018) and Huang *et al.* (2019). Grübler (2003) provides a comprehensive overview of various conceptualizations and terminologies related to technology and its evolutionary processes. Firstly, technology is defined as comprising both hardware and software, encompassing the knowledge required for the creation and use of technological hardware. Secondly, Grübler underscores the fundamental characteristic of technology—its dynamic nature. Technologies exhibit short innovation cycles, typically involving a series of replacements of older technologies with newer ones.

Furthermore, Grübler (2015) highlights the multitude of connections and interdependencies among technologies, giving rise to successive technological "clusters." A pivotal distinction within this terminology lies in the differentiation between invention (discovery), innovation (initial commercial application), and diffusion (widespread replication and growth) of technologies, collectively referred to as the technology life cycle. The process of technological diffusion is of paramount importance in historical technological transformations, particularly concerning global (environmental) changes. The emergence of digital transformation has brought about even more profound disruptions. Initially, digitization involves the material conversion of analog information streams into digital bits (Srai and Lorentz, 2019), while digitalization pertains to the technology used for digitizing information and attributing value (Reis *et al.*, 2020a).

In contrast, digital transformation typically signifies a shift in the business model with technological underpinning (Reis *et al.*, 2018). While military institutions may not have fully embarked on an extensive digital transformation, they appear to be heading in that direction. This transition entails the automation of processes that were traditionally human-driven, often replaced by intelligent machines. Within the domain of technology, literature prominently underscores the concept of Artificial Intelligence (AI), which refers to the capability to replicate human intelligence, encompassing functions such as knowledge acquisition, reasoning, problem-solving, communication, interaction, and learning. Drawing from the frameworks presented by Huang and Rust (2018) and Huang *et al.* (2019), three categories of AI are broadly outlined—mechanical, thinking, and feeling. These categories will be comprehensively explained in the subsequent sections of this thesis.



Turning our attention to the natural environment, the Encyclopedia of Biodiversity (Odum, 2001) offers a comprehensive definition of ecological systems, often referred to as ecosystems. An ecosystem can be characterized as a self-contained unit, a biosystem, encompassing all the organisms within a defined geographical area. These organisms constitute the biotic community, and their interactions with the physical environment result in a dynamic flow of energy, leading to the formation of distinct biotic structures. Furthermore, within ecosystems, there is a continuous cycling of materials between the living organisms and the nonliving components of the environment. In essence, ecosystems are complex webs of life where various species coexist and interact, and energy and matter circulate in a balanced manner. This concept forms the basis for our understanding of the natural world, its conservation, and the critical role it plays in sustaining life on our planet (Adla *et al.*, 2022). Throughout this thesis, we will explore the significance of ecosystems, particularly in the context of the defense industry and military sciences, and their impact on environmental sustainability.

As the defense industry gains renewed traction, exemplified by the research conducted by Simões *et al.* (2020), Reis (2021), and Reis *et al.* (2021a), the need to strategically allocate limited state and private financial resources becomes increasingly vital. This resurgence brings forth new and stimulating opportunities for commercial collaborations. Consequently, this thesis extends beyond its immediate scope, as it is poised to pave the way for a series of N-helices, where the aim is to discover novel relationships that culminate in a systemic innovation model with a distinct focus on the defense domain.

## 1.2. Article Alignment

This thesis comprises a coherent and relevant compilation of scientific articles, each subject to a peer review process and approved by international journal committees. Collectively, this thesis assembles a portfolio of five research articles, all indexed in Elsevier Scopus (Q1–Q2) categories. The assembly of these articles adheres to a comprehensive and cohesive framework, characterized by a broad and original introduction and conclusion. Table 1 categorizes these articles, encompassing social sciences (ID1), applied sciences (ID2), military sciences (ID3) and management (ID4, ID5). As per the guidelines of the *Instituto Universitário Militar* (IUM), this thesis encompasses three published empirical scientific articles, in which the candidate is the first author. ID2 (a literature review) does not align with IUM's stipulations, as it is not empirical; nevertheless, it is included in the



thesis to contextualize the content and facilitate the coherence of the core articles (ID1, ID3, ID4, ID5).

Except for ID1, all the other articles had guest co-authors who contributed to result validation and conducted thorough reviews. Given that four out of the five articles were published in the Multidisciplinary Digital Publishing Institute journals, each author's contributions can be found in the original versions of the articles. The manuscript distribution was planned from both a logical and temporal perspective. The selection included theoretical/technical articles that provided a holistic perspective and in-depth understanding (ID1, ID2), as well as articles involving fieldwork to validate the initial findings (ID3, ID4, ID5). It is worth noting that ID1 and ID3 received the "Scientific Research in Military Sciences" awards from IUM in 2021 and 2022, respectively. Additionally, ID2 was recognized by the Multidisciplinary Digital Publishing Institute as a "feature paper," signifying its potential for significant impact in the field.

Table 1 – Publication program

Original Title	Journal	Status	Indexing	Area	Type
<b>ID1</b> – Politics, Power, and Influence: Defense Industries in the Post-Cold War	Social Sciences – Multidisciplinary Digital Publishing Institute	Published 2021	Scopus Q2 H-Index 27	Social Sciences (Miscellaneous)	Article (Empirical/Theoretical) (Awarded by IUM, see SM1)
<b>ID2</b> – High-Tech Defense Industries: Developing Autonomous Intelligent Systems	Applied Sciences – Multidisciplinary Digital Publishing Institute	Published 2021	Scopus Q2 H-Index 75	Applied Sciences	Review (Feature paper, see SM1)
<b>ID3</b> – Defense Industries and Open Innovation: Dynamics to Increase Military Capabilities of the Portuguese Ground Forces	Defense Studies – Taylor & Francis	Published 2022	Scopus Q1 H-Index 15	Political and Military Sciences	Article (Empirical) (Awarded by IUM, see SM1) (Peer-review, see SM2)
<b>ID4</b> – Quintuple Helix Innovation Model for the European Union Defense Industry – An Empirical Research	Sustainability – Multidisciplinary Digital Publishing Institute	Published 2022	Scopus Q1 H-Index 136	Management and Environment	Article (Empirical)
<b>ID5</b> – Green Defense Industries in the European Union: The Case of the Battle Dress Uniform for Circular Economy	Sustainability – Multidisciplinary Digital Publishing Institute	Published 2022	Scopus Q1 H-Index 136	Management and Environment	Article (Empirical) (Peer-review, see SM2)

Source: Own authorship



### 1.3. Materials and Methods

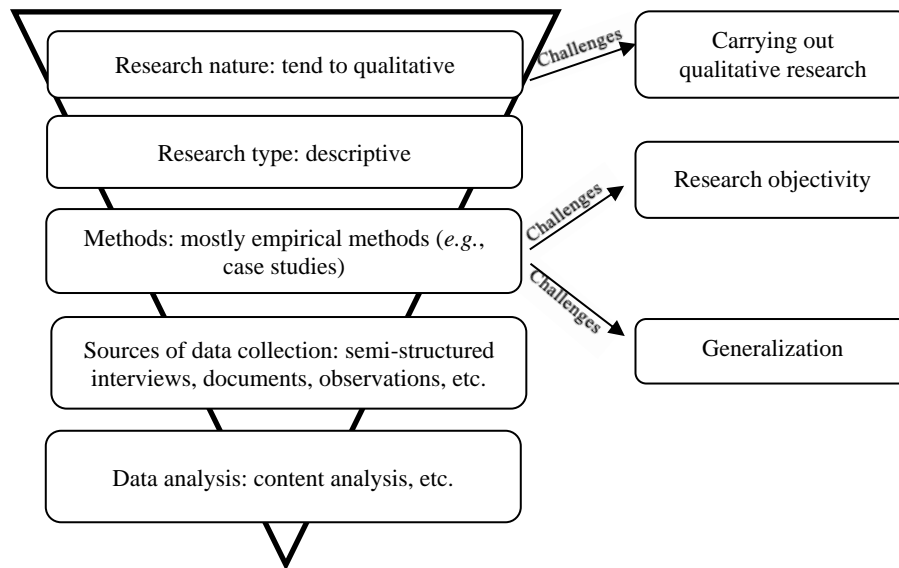
This thesis generally adopts a qualitative methodology and descriptive research techniques to investigate and elucidate various behavioral phenomena. As stipulated in Article 27, Chapter VI of the Regulatory Norms for the Doctorate in Military Sciences, are mandatory to incorporate at least three scientific articles emanating from empirical studies. To meet this requirement, we have included the [ID1](#) article in the thesis, which employs a quantitative approach in the form of bibliometric analysis. This methodological choice leverages statistical techniques to scrutinize data extracted from diverse sources, including peer-reviewed journal articles, books, conference proceedings, journals, reviews, brief surveys, and associated documents (Ahamer & Kumpfmüller, 2014; Kulakli, 2021). Furthermore, as previously mentioned, the inherent nature of this study leans towards a qualitative approach, driven by the goal of gaining a comprehensive understanding of the defense industry phenomenon under investigation. The predominant research methodology employed here is non-experimental, characterized by descriptive case studies. This choice is twofold: firstly, it aligns with the study's primary objective of understanding the phenomenon, and secondly, it proves advantageous when dealing with an extensive volume of available data (Thorpe & Holt, 2007). This approach is especially pertinent for investigating real-world phenomena, as it allows for a rich contextualization of the subject (Yin, 2018).

According to Kothari (2004), empirical research relies on data to draw conclusions that can be validated through observation or experimentation. This form of research is sometimes termed experimental, as it frequently prioritizes data collection over theoretical considerations. In this type of research, it is necessary to directly access factual information at its source to generate the desired insights. Conversely, Kothari (2004) contends that conceptual research revolves around abstract ideas or theories. It is commonly employed by philosophers and intellectuals to formulate new concepts or reinterpret existing ones. Within this thesis, the sole purely theoretical contribution can be found in article [ID2](#), which allowed to strengthen the existing body of literature and provide support for the empirical studies. However, it is essential to acknowledge a pertinent concern regarding qualitative empirical research, as it often faces criticism for its limited potential for generalization (Bloor & Wood, 2006). In the context of the case studies presented in this thesis, we employed a variety of data collection sources, including (1) semi-structured interviews, involving recordings and transcripts, (2) analysis of official documents, and (4) direct observations, encompassing



field notes and informal conversations. These methods were applied to gather insights from several key players, constituting the unit of analysis. Notable entities among them include idD – Portugal Defense, the Portuguese Defense Technological Industrial Base (DTIB), the European Union (EU) Armed Forces, Universities, and Supranational Agencies. Figure 2 provides a concise summary of the information presented in this section.

**Figure 2** – General description of the scientific research process



Source: Adapted from Yin (2018)

The core objective of this research is to find scientific evidence by corroborating data and to respond to the research questions that uphold both validity and reliability. Employing these data collection techniques is instrumental in enhancing transparency throughout the study. In the following sections, we elucidate the methodology employed during the exploratory phase of this thesis, encompassing interviews, interview protocols, and the case research protocol (as illustrated in Figure 3).

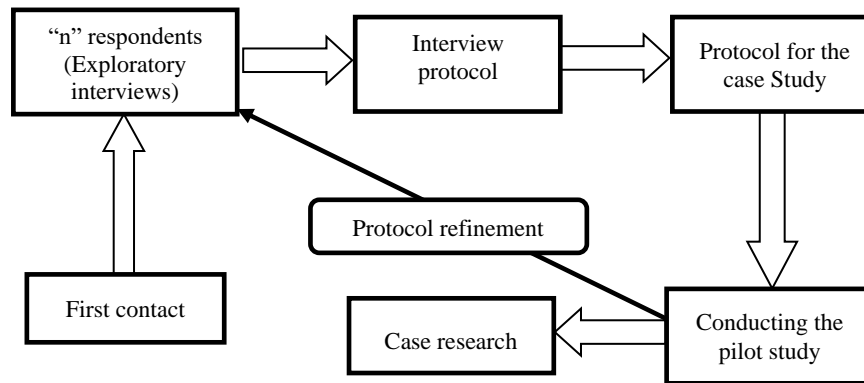
*Exploratory Interviews* – According to Yin (2018), case research is typically an extensive and time-consuming endeavor, a challenge that can be mitigated through the strategic use of exploratory interviews. This approach is often hailed as a valuable technique across various research domains. Through exploratory interviews, the theoretical field was more precisely delineated, aiding researchers in clarifying their focus. Essentially, these interviews served as beacons, helping to sift through unsuitable ideas, generate new avenues for reflection, and chart the correct course. Although not documented in the formal articles, exploratory interviews were frequently employed, predominantly through informal conversations and telephone calls.



*Interview Protocol* – The development of the interview protocol commenced with the initial engagement of respondents. In essence, after crafting the conceptual frameworks (ID3, ID4, ID5), questions naturally surfaced. Some of these questions found resolution within the exploratory phase, facilitating the operationalization of the interview protocol. Through the initial exploratory interviews, the researcher had the invaluable chance to not only elucidate the research boundaries but also to refine and validate the protocol that would be employed in the final interviews.

*Case Study Protocol* – The questions derived from the interview protocol were integrated into the case study protocol. Prior to the data collection phase, these questions underwent thorough validation and testing processes. The case study protocol included a dedicated section (column) indicating the appropriate data collection techniques for each question from the interview protocol, facilitating a comprehensive alignment of methodologies.

*Pilot Study and Protocol Effectiveness* – Recognizing the complexities of our research questions, we deemed it necessary to conduct a pilot study before exploring extensive data collection, such as many interviews. The questions derived from the exploratory interviews, which were integrated into the pilot study, played a pivotal role in assessing the protocols' effectiveness, ensuring more coherent and consistent answers. Throughout the assessment of the protocols' effectiveness, we identified areas for refinement in the final set of questions. The execution of the pilot case study significantly enhanced the likelihood of success in the overall research endeavor. In practical terms, the pilot study was executed through article ID3, where initial indications suggested that the defense industry operated within a quintuple-helix framework, though uncertainties persisted. Article ID4 then confirmed this quintuple-helix structure, while article ID5 explored deeper into the discovered options, , providing additional support to strengthen the thesis.

**Figure 3** – Exploratory phase of the research

Source: Adapted from Yin (2018)

In summary, following initial engagements with the mentioned unit of analysis, the researcher conducted a series of preliminary interviews. These interviews were instrumental in narrowing down the theoretical scope and establishing a clear direction for developing the interview protocol. Subsequently, with the interview protocol in place, the researcher proceeded to outline a comprehensive case study protocol. The pilot study played a crucial role in assessing the efficacy of the protocols and laid the groundwork for the subsequent in-depth case study. Once the protocols had been defined, the research moved into the data collection and fieldwork phase. This phase encompassed a diverse array of data sources, which we will elaborate on below.

*Interviews* – In our research, the interview process involved a careful selection of respondents based on non-probabilistic criteria, employing a combination of convenience and snowball sampling methods as outlined by Berg (2004). Snowball sampling has gained popularity, especially among scholars interested in the study of various behaviors, sensitive subjects, or hard-to-reach populations, as noted by Bloor and Wood (2006). Despite the challenges associated with securing institutional access, we aimed to encompass a broad spectrum of functional areas and hierarchical levels. Within this context, our implementation of snowball sampling entailed procuring interviews through the social networks of previous participants, following the methodology outlined by Fisher *et al.* (2007). Given the nature of our research focus, we concluded that employing semi-structured interviews was the most effective approach. This format allowed participants to articulate their thoughts coherently and align their responses with the phenomenon under investigation. To maintain confidentiality, we conducted a limited number of interviews, a count justified by the achievement of theoretical saturation. The concept of saturation, as described by Saunders



and Townsend (2016), served as a compelling rationale for determining the appropriate number of participants. Some researchers have upheld saturation as a guiding principle when deciding on participant numbers. The primary objective of our interviews was to glean fresh insights that could be substantiated by other data sources, reinforcing the robustness of our research findings.

*Direct Observation* – Observation played a relevant role in our data collection, entailing a systematic and meticulous immersion in the subject, as stressed by Taylor-Powell and Steele (1996). This approach enabled us to initiate a comprehensive process of analytical interpretation, aligning with the insights put forth by Saunders and Lewis (2007). Throughout our research, the researcher engaged in a series of informal conversations, which served to enhance our understanding of the data garnered through formal interviews. In essence, the field notes derived primarily from the nuanced analysis of the phenomenon under study and the informal dialogues conducted, all with the central objective of reinforcing the validity of our findings.

*Official documentation* – Official documentation included all information coming from the units of analysis. In this technique, our primary source of data was resulting from official websites, internal reports, and other pertinent sources. While this data collection method was not given precedence, it served a crucial role as part of our triangulation approach. Our use of official documentation aimed at enriching and substantiating the insights obtained from interviews, thereby validating select reports—a strategy akin to what Yin (2018) underscores as a significant aspect of case studies. Internal documents assume particular importance as they contribute additional layers of evidence from diverse data collection sources. In cases where evidence presented contradictions rather than corroboration, we undertook in-depth investigations into the matter. This rigorous process involved collaborative efforts between researchers and respondents to reach a consensus, as emphasized by Yin (2018).

In addition to the primary methods and data collection sources detailed earlier, we also incorporated various secondary methods and sources to complement our research efforts. Below, we outline some of these secondary methods, although our published articles may encompass a broader array of such techniques.

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) – The PRISMA protocol was utilized as a supplementary submethod, identified as ID5 in our research. This approach involved the implementation of a comprehensive 27-item checklist

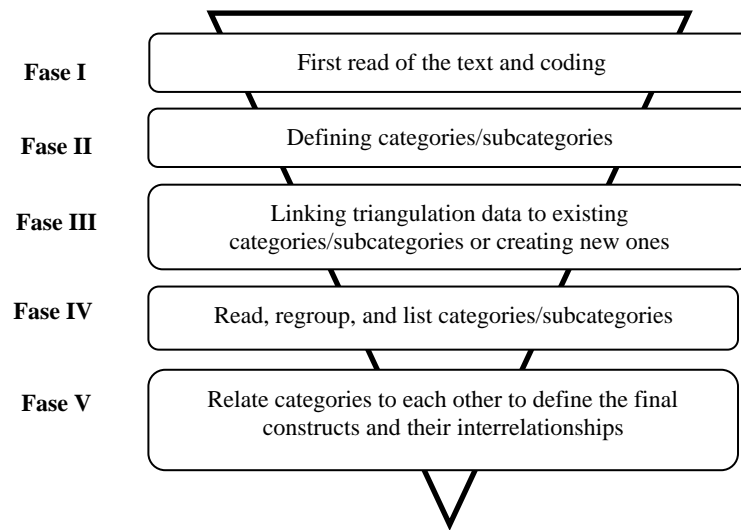


and a four-phase flow diagram, following the framework established by Moher *et al.* (2009). PRISMA was predominantly employed in conjunction with Elsevier's Scopus as a data collection source due to its capacity to yield a larger volume of relevant literature and facilitate precise searches within the domain of military sciences. The primary objective behind incorporating the PRISMA statement was to enhance the reporting quality of systematic reviews and augment the transparency of our research. As elucidated by Moher *et al.* (2009), PRISMA can also be a valuable tool for critically assessing published systematic reviews. However, it is important to understand that the PRISMA checklist does not serve as a quality assessment instrument for gauging the overall quality of a systematic review. To fulfill this purpose, we employed the Critical Appraisal Skills Programme (CASP Checklist).

*Critical Appraisal Skills Programme (CASP)* – CASP was integrated as an adjunctive sub-method, essentially serving as a qualitative checklist complementing the PRISMA approach. Functionally, CASP enabled us to scrutinize articles sourced from Elsevier's Scopus database using a ten-point scale. This program held particular interest as it facilitated the evaluation and categorization of articles selected from the database, aiding in the identification of central topics for our analysis. In the [ID5](#) article, CASP was further enhanced with the inclusion of Scimago Journal & Country Rank (SJR), an internationally recognized open-access platform that assists in evaluating the quality standard (quartile) of journals.

*Synthesis Report (Synth Rep)* – Finally, our research endeavors culminated in the creation of a comprehensive synthesis report. This report aimed at consolidating existing knowledge within the defense industry, offering a holistic perspective on the available literature, as exemplified in [ID5](#).

The final stage depicted in Figure 2 entails data analysis. We conducted a comprehensive analysis of the data in four distinct phases, employing the content analysis technique as explained by Mills *et al.* (2010). To facilitate this data analysis endeavor, we leveraged software tools. These tools streamlined the process, allowing the researcher to efficiently code and categorize extensive volumes of textual data. The systematic data coding process is structured in alignment with the framework depicted in Figure 4.

**Figure 4 – Coding process**

Source: Adapted from Given (2008)

The coding process assisted as a systematic and iterative method for refining information until we derived our results. This process unfolded in four key phases: (1) Initial data review—in the first phase, we conducted a thorough review of all available textual data, initiating the coding process; (2) Category establishment—the second phase involved the definition of a comprehensive set of categories and subcategories, in line with Given's approach (2008). These categories were created based on terms and expressions extracted from diverse data collection sources. (3) Alignment with existing literature—the third phase centered on linking the data with our existing literature review. This step allowed us to create new categories where necessary and corroborate existing ones. (4) Category prioritization – in the fourth and final phase, we reorganized the categories based on their significance. This involved a detailed examination, reordering, and exploration of interrelationships among categories. In summary, our methodology relied on a triangulation approach, and we used Computer-Assisted (or Aided) Qualitative Data Analysis Software (CAQDAS), specifically NVivo 11 & 12, to facilitate this comprehensive analysis.

#### **1.4. Research Questions and due Discussion**

In this section, we introduce the Research Questions (RQ) along with their corresponding discussions, as outlined in Table 2. The first article explores the relationship between the defense industry, the nature of warfare, and the dynamics of political power. While RQ1 did not yield promising results, the findings for RQ2 proved to be highly relevant, justifying the publication of the article. The second article focused on the



technological issue, categorizing it into different modes within each level of warfare. The third article centers its focus on open innovation and the concept of the quintuple helix, aligning with the thesis title and research objective. The fourth and fifth articles provide in-depth explorations of two specific helices: technology and the environment, respectively. Each of these articles explores deeply each of the latter helices.

**Table 2** – Research questions summary

Title	Research Question (RQ)
<b>ID1</b> – Politics, Power, and Influence: Defense Industries in the Post-Cold War	RQ1: How is the nature of war influencing the defense industry in the post-Cold War?
<b>ID2</b> – High-Tech Defense Industries: Developing Autonomous Intelligent Systems	RQ2: How can the industrial defense sector contribute to the stratification of political power in the international system as a stabilizer or catalyst for wars and conflicts?
<b>ID2</b> – High-Tech Defense Industries: Developing Autonomous Intelligent Systems	RQ3: How can the several modes of autonomous defense systems in the defense industry be categorized?
<b>ID2</b> – High-Tech Defense Industries: Developing Autonomous Intelligent Systems	RQ4: How does the characterization of the autonomous defense systems modes contribute to making the defense industry highly technological?
<b>ID3</b> – Defense Industries and Open Innovation: Dynamics to Increase Military Capabilities of the Portuguese Ground Forces	RQ5: How is OI improving the defense industry and increasing military capabilities?
<b>ID3</b> – Defense Industries and Open Innovation: Dynamics to Increase Military Capabilities of the Portuguese Ground Forces	RQ6: How is the QH innovation model energizing the military capabilities of ground forces?
<b>ID4</b> – Quintuple Helix Innovation Model for the European Union Defense Industry – An Empirical Research	RQ7: How does the European Defense Industry operate in the N-Helix model?
<b>ID5</b> – Green Defense Industries in the European Union: The Case of the Battle Dress Uniform for Circular Economy	RQ8: How to properly carry out a green transition of the EU defense industry?

Source: Own authorship

*RQ1*: How is the nature of war influencing the defense industry in the post-Cold War? (see Table 2 – sourced from **ID1**). Upon reviewing the existing literature, we have discerned that there is not a direct and linear connection between the evolving nature of warfare and the advancements within the defense industry. Instead, it is the decisions and investment intentions of states that wield significant influence over the growth and trajectory of this industry. A case in point is the aftermath of the 9/11 events, where the United States military intervention in Afghanistan and Iraq had a profound ripple effect, revitalizing the global defense industry. This serves as a compelling example of how state actions can reinvigorate and shape the landscape of the defense industry worldwide.

*RQ2*: How can the industrial defense sector contribute to the stratification of political power in the international system as a stabilizer or catalyst for wars and conflicts? (see Table



2 – sourced from ID1). Regarding the dynamics (stratification) of political power within the international system, we can identify three fundamental approaches: integration, autarky, and domination, whether with or without state support. One example of integration is the EU, which has pursued integration with limited power stratification. This approach makes it less likely to act as a catalyst for war or conflict. Autarky, on the other hand, represents the pursuit of independence or self-sufficiency within the defense industry, often reliant on substantial state aid. A pertinent illustration is Turkey's defense industry. In the case of domination, it becomes imperative to promote government-funded programs aimed at leveraging the defense industry, thereby enabling states to emerge as influential actors on the international stage. The People's Republic of China stands as an example of such domination, actively seeking regional dominance through military diplomacy and strengthening military ties with neighboring nations, with the strategic aim of undermining potential adversaries.

*RQ3:* How can the several modes of autonomous defense systems in the defense industry be categorized? (see Table 2– sourced from ID2). In the domain of defense, intelligent autonomous systems can be classified into three distinct modes: fully autonomous operations (Mode 1), partially autonomous operations (Mode 2), and intelligent autonomous decision-making (Mode 3). At the tactical level of warfare, military actions necessitate standardized decisions (Mode 1). However, it is worth noting that over the medium and long term, machines are likely to supplant humans in executing these standardized and analytically driven decisions. Consequently, intelligent autonomous systems are poised to assume an increasingly significant role in tactical warfare. Mode 2 is ideally suited for the operational level of warfare. Here, humans often grapple with semi-structured decisions, which carry a moderate degree of responsibility. In such scenarios, machines may assume control, particularly in areas where standardization plays a role. Meanwhile, Mode 3 is well suited in the context of strategic military operations. In this domain, humans frequently encounter complex, unstructured decisions that demand a high level of responsibility. Autonomous defense systems should be viewed as supportive tools for humans rather than replacements in the decision-making process.

*RQ4:* How does the characterization of the autonomous defense systems modes contribute to making the defense industry highly technological? (see Table 2 – sourced from ID2). Each mode plays a distinct role in enhancing the technological landscape of the defense industry. Scientific research and development in military technologies tend to concentrate



on the first two levels of warfare, specifically the tactical and operational levels. This emphasis is attributed to the fact that these modes offer fertile ground for technological innovation. In contrast, the strategic level presents a unique challenge. It involves decision-making with a strong empathic dimension, an area where technological applications are currently limited. Consequently, strategic-level decision-making is expected to remain primarily in the hands of human operators. In summary, looking ahead to the medium and long term, automation in Mode 3 is likely to experience more constraints compared to Mode 1, given the inherent complexity of empathic decision-making within strategic contexts. This balance between human expertise and technological automation underscores the multifaceted nature of technological progress within the defense industry.

*RQ5:* How is Open Innovation (OI) improving the defense industry and increasing military capabilities? (see Table 2 – sourced from ID3). OI has ushered in a transformative era for the defense industry by fostering collaboration among universities, businesses, and government entities, often referred to as the "triple helix". In the article ID3, we observed that this paradigm shift has yielded significant benefits, particularly for ground forces, since their survivability on the battlefield has been increasing. Within the broader framework of the "quintuple helix," there are plans to market new military products to foreign military markets. This endeavor is expected to facilitate the transfer of knowledge to companies engaged in projects or consortia, enabling industrialization, and ensuring their entry into the civilian market, a concept known as "dual use." Beyond these collaborations between military and business sectors, the university's role in knowledge production opens avenues for further innovation and technological development (R&DT). This encompasses scientific research output and the development of patents. In essence, OI in the defense industry not only fosters cooperation between military entities and the business community but also spurs knowledge creation in universities, thereby fueling a broader spectrum of innovation and technological advancement.

*RQ6:* How is the Quintuple Helix (QH) innovation model energizing the military capabilities of ground forces? (see Table 2 – sourced from ID3). Within the context of the QH framework, we have observed that the development of products within the defense industry has transcended considerations beyond the traditional three helices, including environmental concerns. For instance, the adoption of fibrous materials like high-performance polyethylene fiber has brought about remarkable improvements in equipment capabilities, as well as enhancing the comfort and ergonomics of Portuguese military gear.



The reduction in weight and ergonomic enhancements have, in turn, contributed to the enhancement of military capabilities. This includes enabling greater speed and mobility on the battlefield, exemplifying how certain military technologies can fortify and safeguard military forces within the QH innovation model. Our exploration of this question has yielded preliminary results, and we anticipate exploring deeper into this subject in subsequent articles ([ID4](#) and [ID5](#)) to gain a more comprehensive understanding of the impact of such innovations within the defense industry.

*RQ7:* How does the European Defense Industry operate in the N-Helix model? (see Table 2 – sourced from [ID4](#)). The Triple Helix (TH) model, while valuable, is no longer adequate nor fully aligned with the evolving landscape of the defense industry, which encompasses a significantly broader spectrum of stakeholders and influences. This assertion is substantiated by the increasing convergence between the defense sector and academic institutions, while the relationship with government entities has shown signs of diminishing strength. This shift is largely attributed to the forces of globalization, which have propelled the Portuguese defense industry beyond national boundaries in pursuit of synergies within the broader European and international contexts. Our research indicates that the defense industry now operates within the framework of the Quintuple Helix model, with a predominant focus on technology and the natural environment. In the domain of environmental considerations, the findings present a mixed picture. On one hand, there is a discernible uptick in efforts to integrate environmental concerns across the entire technological production spectrum, encompassing development, testing, and implementation phases. However, it is noteworthy that theoretical studies examining the intersection of the natural environment and the defense industry remain scarce, and empirical analyses on this subject are crucial. These aspects are explored in greater detail in article [ID5](#), shedding light on the relationship between the defense industry and environmental sustainability.

*RQ8:* How to properly carry out a green transition of the EU defense industry? (see Table 2 – sourced from [ID5](#)). Our analysis reveals that the green transition within the European Union's defense industry is fundamentally underpinned by the principles of a Circular Economy (CE). This subject remains relatively underexplored within the academic community. According to insights from [ID5](#), CE policies in the EU's defense industry are characterized by ambitious objectives, prominently focused on protracting the lifespan of defense products and their constituent parts, as well as the development and manufacture of



more intelligent defense products. The [ID5](#) article has discerned a compelling nexus between technology and environmental sustainability. For instance, we underscored the application of cutting-edge technologies to engineer sturdier and longer-lasting defense materials. This approach facilitates leaner strategies with reduced resource and energy consumption. Furthermore, the article illustrates instances where projects have been initiated to create technological solutions that integrate multiple attributes within a single defense product. Such initiatives have the dual advantage of curtailing the need for additional equipment while enhancing the efficiency and accessibility of the defense industry. The green transition of the European Union's defense sector must be ensured by adhering to the empirical framework and implementing the identified R-strategies. The exemplified case within the defense industry framework successfully encompasses six out of the nine identified R-strategies. While the generalizability of these findings may have limitations, they offer promise for the broader context. Therefore, we advocate for heightened discourse and collaboration among European Union member states to collectively pursue circular economy objectives within their respective armed forces. Additionally, aligning strategies and fostering benchmarking initiatives among member states could prove invaluable in advancing the green transition agenda.

When we align the research questions, it becomes evident how the articles collectively trace the evolution of the innovation model toward the quintuple helix. In the following section, we will present an integrated summary of the existing literature.

### **1.5. State of the Art**

One of the first studies on the Portuguese defense industry and OI models was conducted by Simões *et al.* (2020). This research reported the characteristics of the defense sector, involved with national sovereignty concerns. Despite historical demarcations between the military and civilian domains, this study revealed a noticeable uptrend in dual-use projects, highlighting a growing convergence of interests. The article analyzes the network of relationships within the defense industry, seeking to unravel the dynamics within the triple helix that governs this specialized sector. A key finding of this investigation was the substantial representation of academia, contributing to over 90% of the projects. 40% of these projects exhibited dual-use potential, suggesting their applicability in both military and civilian contexts. From these findings, two significant conclusions emerge.



First and foremost, there is a pressing need to integrate the Portuguese Armed Forces into academia. The current framework for the development of military equipment and technologies adheres to a triple collaboration model: Universities-Industry-Armed Forces. However, it is crucial to note that this triple helix model has traditionally involved civilian universities primarily focused on intellectual property development, alongside the defense industry and technology parks responsible for the equipment/technology development and production. Meanwhile, the Armed Forces have often played a critical role in the final stages, primarily encompassing testing and certification, as exemplified by certifications such as the "PRT Army Tested" and "Combat Proven Certificates". Although the triple helix model has been effectively employed in Portugal, as evidenced by initiatives like the Consortium Auxdefence, there exist significant opportunities for the Portuguese Armed Forces. Specifically, by actively engaging with the academic community and developing capabilities, such as the Doctorate in Military Sciences, military universities, and research centers can strategically position themselves further upstream within the triple helix framework. This rationale forms a substantial part of the motivation driving this thesis. The objective is not to overhaul the existing triple helix context but rather to demonstrate the potential of the Armed Forces, including the Instituto Universitário Militar (IUM) and its Autonomous Organic Units, to add dynamics to this collaborative model. This transformation can be realized through a concerted effort in scientific research and the promotion of academic production. The aim is to facilitate the downstream development of technologies and/or military equipment by the military personnel themselves. It is crucial to underscore that our recommendation is not to put aside the triple helix but to showcase how the Armed Forces, the IUM, and their respective research centers can enrich and enhance this collaborative structure. This endeavor has been advanced through various means, including the publication of international scientific articles in renowned Scopus Q1 and Q2 journals and the pursuit of doctoral theses. The cumulative result of these efforts has culminated in the development of an empirical quintuple helix model tailored to the defense industry.

Secondly, our forthcoming endeavors will involve translating the findings of this thesis into tangible outcomes, thereby addressing concerns from critics who argue that theoretical knowledge often remains abstract. Within this framework, we outline the subsequent phases of our research as future initiatives, providing a concise overview of a project that has already



been submitted and approved. This project is designed to operationalize and manifest the theoretical insights we have gleaned.

Lorenzo *et al.* (2021) analyzed the defense industry through the lens of the Carayannis & Campbell (2010) quintuple helix model. Within their framework, these authors assert that the establishment of a robust defense industry hinges on the identification and efficient interaction of various actors, both from the public and private sectors. Such interactions are deemed essential for fostering a sustainable innovation model capable of reducing external technological dependencies. According to their perspective, a comprehensive innovation model for the defense industry necessitates the active involvement of five key agents: government, academia, industry, society, and environmental agencies/organizations. However, this thesis contends that the fourth dimension of this model primarily revolves around technology. Considering this perspective, we derive two key conclusions. First, it is relevant to recognize that technological advancements within the defense industry exert an influence on society at large. In this thesis, we show the potential of auxetic composite materials, which hold immense promise for applications where energy absorption plays a pivotal role in ensuring protection. Examples include their application in sports activities (Steffens *et al.*, 2021), aerospace endeavors (Wang *et al.*, 2016), and various other domains. Consider, for instance, Unmanned Aerial Vehicles (UAVs), initially designed for military purposes but now finding utility in civil contexts as well. They are employed by state organizations, such as aiding in forest surveillance and fire detection as part of operations supporting the special apparatus for combating rural fires in Portugal. This adaptation underscores how defense technology can be repurposed for societal benefits. Furthermore, Kurian (2000) aptly observed that technology-intensive defense industries in the People's Republic of China wielded a significant social impact, primarily due to their dual-use capabilities, bridging the military-civilian divide to drive national economic modernization. Considering the above, it becomes evident that the extent of technological progress within the defense industry is directly proportional to the advantages it confers upon civil society.

Second, we have identified a nexus between technology and the natural environment. As early as 2014, Fiott articulated that European militaries, institutions, and defense industries have exhibited a strong commitment to environmental sustainability. Within the European Union (EU), the process of "greening" the defense sector encompasses a spectrum of initiatives, spanning increased scientific and academic research endeavors to rigorous adherence to environmental and circular economy policies. To facilitate this transition,



universities, and technology parks have a pivotal role to play in developing the requisite technologies essential for realizing this green transformation. Consequently, it is incumbent upon the defense sector and its stakeholders to embrace an eco-conscious approach. This entails an understanding of the ramifications of climate change and a proactive role in the development of technologies aimed at mitigating its impact. Such endeavors, in turn, foster greater self-sufficiency and resilience within the sector. Drawing upon the empirical evidence it becomes evident that the fourth dimension of the quintuple helix model, revolving around technology, assumes the pivotal role of constructing a bridge between society and the natural environment (quintuple helix), catalyzing cohesive collaboration in this interconnected ecosystem.



## 2. Chapter II – Politics, Power, and Influence: Defense Industries in the Post-Cold War (ID1)

### Executive Summary<sup>1</sup>

This inaugural article, which forms a foundational component of this thesis, offers a comprehensive and theoretical examination of the defense industry, with a particular focus on the post-Cold War era. Regarding the Cold War's conclusion, both NATO and the defense industry encountered a crossroads. For the defense sector, this meant grappling with the dual challenge of ensuring global military readiness within constrained budgets and uncertain delivery timelines, while simultaneously serving as a linchpin for national sovereignty and foreign policy. Presently, considering the ongoing conflict in Ukraine, the significance of NATO's existence and the imperative for a robust defense industry to support it has become increasingly evident, not to mention the importance of supporting the EU and other key stakeholders. Therefore, despite this article's antecedent publication before the Ukrainian conflict, its relevance endures. The article's primary objective at the time was to delineate the state of current literature and explore research domains, laying the conceptual groundwork for future empirical investigations. To this end, this study employed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement, a suitable approach for uncovering fundamental concepts, ideas, and debates surrounding the defense industry. The study's findings revealed three distinct approaches to the defense industry: integration, autarky, and domination. Within this context, numerous case studies were presented, illustrating instances where the defense industry serves as an instrument of foreign policy or national sovereignty. As evidenced in this article, the defense industry itself is not inherently a catalyst for conflict or warfare. Rather, the effective coordination of defense policies, particularly within the EU, enhances the resilience and preparedness of the defense industry. In theory, this fosters long-term coordination, collaboration, and integration among Member States. This coordinated effort is indispensable, as it offers

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<sup>1</sup> This executive summary serves as an expanded version of the initially published abstract, providing a comprehensive understanding and ensuring alignment among the thesis articles. For citation guidance, please refer to the APA standards. For chapter citation: Reis, J. (2021). Politics, power, and influence: Defense industries in the post-Cold war. *Social Sciences*, 10(1), 10. <https://doi.org/10.3390/socsci10010010>. For thesis citation: Reis, J. (2023). Development of an N-Helix Innovation Model for the Portuguese Defense Industry. Military University Institute. Portuguese Ministry of Defense.



collective action benefits, such as specialization gains for competitive advantages in military technology development, economies of scale, and most significantly, heightened interoperability among EU nations. However, achieving interoperability between the EU and NATO remains a complex challenge, though we will not explore it in this article. Instead, we will later investigate the existence of a gap in procurement coordination between the EDA (European Defense Agency) and the NSPA (NATO Support and Procurement Agency). To a large extent, this limitation can be attributed to varying degrees of confidentiality between the EU and NATO. Nevertheless, the NSPA plays an active role within the EU concerning the defense industry. Considering the current situation (September 2023), the significance of the EU defense industry in providing both lethal and non-lethal military means and technologies to Ukraine is quite clear. This is essential to ensure the defense and security of the European Union. Consequently, military resources and technologies are not only vital for Common Security and Defense Policy (CSDP) missions outside the EU, but also within Europe itself. However, the standardization of military materials remains a challenge and is not addressed in this thesis due to the complexity of the subject and the extent of scientific exploration it requires. In conclusion, this article underscores the importance of future empirical studies that can validate theoretical findings or identify variables that drive certain defense industries to seek synergies through mergers and acquisitions, while others opt for state funding. While the subsequent articles in this thesis delve into the high-technology and quintuple helix defense industry, incorporating environmental considerations, this recommendation for future research remains particularly pertinent, especially for a more in-depth understanding of how the EU operates, particularly in terms of the integration approach.

**Keywords:** politics; defense industry; post-cold war; crisis; war

## 2.1. Introduction

In the post-Cold War period, the defense industry had a major influence on the hierarchy of State powers (Neuman, 2010); however, the defense sector received little or no attention from scholars and professionals, which justifies this research.

Since the end of the Cold War, the defense industry changed, as the nature of war shifted from large arsenals to highly innovative and highly accurate weapon systems (PwC, 2005). Thus, the defense industry had to adapt to survive to reduce costs and expand its influence,



while, equally importantly, the State reduced its participation in sustaining defense research (Chin, 2019). As a result, defense companies began to form multinational corporations and establish transnational networks, expanding beyond State borders and, in some situations, replacing intergovernmental cooperation (Kurç & Neuman, 2017). Further analysis showed that this transformation has the potential to influence international politics, crises, and armed conflicts (Neuman, 2006). In other words, the security community seemed to be more interested in collaborating to respond to regional outbreaks of minor conflicts rather than preparing for conventional wars.

Further on, 9/11 brought a new change, as regional conflicts globalized due to the necessary fight against international terrorism (Kellner, 2007). Thus, the defense spending had to be adjusted, becoming more flexible in response to unexpected situations, which influenced the entire supply chain of the defense industry. Nowadays, the defense industry is (again) at a crossroads, as it is under great pressure to guarantee the current war efforts are carried out within uncertain deadlines and tight budgets, which raises questions about who finances global wars and how to do so.

Although there are few studies about this problem, notable research by Neuman (2010) discussed the global defense industrial sector in the post-Cold War. In that regard, the author argues that the United States of America (USA) dominated the global defense industrial systems by imposing major restrictions on the political choices of most States, including the other arms-producing countries that remain hostage, as sales and advanced technologies remain dependent on the USA, which increases the latter's political influence. According to Neuman (2010), the defense sector provides U.S. policymakers with a powerful foreign policy tool to penalize uncooperative behavior, reward cooperation, promote stability, and pursue vital U.S. foreign policy interests.

Despite the previous contribution, as far as we know, no article thus far has focused on how the nature of war has influenced the defense industry, which is the gap identified in the literature. Moreover, there are questions about how the defense industry is stratifying the political power in the international system. In that regard, Meijer (2010) research shed some light on the attempt to distribute power among other relevant players. While the author argues the transformations of the European Union's defense industry and political initiatives in the post-Cold War era gradually eroded American preeminence, he reinforces the idea that a shift in the market power is moving toward Europe. The defense industry and the military technological developments reduce the opportunities for war, for example, nuclear



deterrence; on the other hand, the arms race also generates new opportunities and facilitates new forms of conflict (Chin, 2019), affecting the character of war and the polarization of politics between States with greater and lesser military power. That said, we developed two research questions (RQ), as follows:

RQ1: How is the nature of war influencing the defense industry in the post-Cold War?

RQ2: How can the industrial defense sector contribute to the stratification of political power in the international system as a stabilizer or catalyst for wars and conflicts?

The next section of this article describes the conceptual background, where the main concepts are presented; a description follows of the methodological process, where each phase of the systematic review is explained; the results are divided into (1) a bibliometric analysis, where a series of graphics retrieved from Scopus allows a visual analysis, and (2) a content analysis, where an overview of the state-of-the-art is provided; finally, the conclusion discusses theoretical and practical implications, limitations of the research, and recommendations for future studies.

## **2.2. Conceptual Background**

Although it is a challenge to define such relevant concepts as politics, power, crisis, conflict, or war, our intention is not to present formal definitions but rather to stimulate the discussion to familiarize the reader with the conceptual foundations, which will be useful to understand the results of this study.

### **2.2.1. Politics, Power, and Influence**

Buchanan and Badham (2020) recently argued that power is a “contested concept”, thus there is no consensus around its nature and definition. That is true; however, Russell (2004) once argued that “the fundamental concept in social science is power, in the same sense in which energy is the fundamental concept in physics”, which is quite an interesting thought. A more recent discussion stimulated by Galinsky *et al.* (2003, p. 454) reinforces that academics when referring to power traditionally emphasize its determinants, which include “basic human motives; individual-difference variables such as authoritarianism and motivational style; interpersonal variables such as control, dependence, and social change; and socio-structural variables such as relative expertise and legitimate authority”. In addition, Galinsky *et al.* (2003) argue that power is the ability to control resources, one’s own and others, without social interference and that, when experienced, it has metamorphic



effects. In that regard, Keltner *et al.* (2003) made a distinction focusing on the actor's intentions and actions, such as domination and social power activities but also highlighting the target's response to the actor, such as power as influence. Therefore, in general terms, power can be identified as the ability to control the intention and the actions of others, while influence can be seen as a reaction of the targets of that power, whose search for zero-sum games is frequent to avoid domination. Not very different is politics, which is closely related to power. Politics consists of controlling human behavior through voluntary obedience habits in combination with threats or probable coercion (Deutsch, 1967). However, in the conceptual horizon, we were able to identify several terms that are not synonymous, such as policy, politicking, polity, and politicization. In that concern, Palonen (2003, p. 171) defines "policy as the regulating aspect of politics, politicking alludes to a performative aspect, polity implies a metaphorical space with specific possibilities and limits, while politicization marks an opening of something as political, as playable". In early 2000, the concept of "depoliticization" also became popular, as Wood (2016, p. 2) argues, "neoliberal policies for privatization, deregulation, and labor market discipline gained strength worldwide, leading to discussions about an alleged 'end of politics' and the rise of 'post-democracy'".

### **2.2.2. Crisis, Conflict, and War**

In the mid-90s, Brecher (1996) carried out research on crisis, conflict, and war; in light of the above, the author commented that the terms are conceptually and empirically interrelated, while all are characterized by mutual mistrust between adversaries, turmoil, tension, and hostility. Consequently, violence as an essential trait of war is not often present in crisis and conflict (Brecher, 1996, p. 127). Crises are usually identified as events that seriously disturb the functioning of organizations, sectors, or nations (Laws & Prideaux, 2006; Lebow, 2020). Conflicts can be seen as situations where there are different perspectives, goals, objectives, or politics that may be irreconcilable between various parties (Azis, 2009). A more complex concept is that of war (Dimitriu, 2020), where the factual sense of hostilities involves the use of armed forces between States and where the rules of international law exist to regulate it (Greenwood, 1987). Although the expression "war against terrorism" (Greenwood, 2002; Sanyal, 2020) has led us to believe in a correspondence of terrorism with war, the concept of terrorism has been identified as a crime (Jenkins, 1985), or, in Fletcher's (2006) understanding, a super-crime, that incorporates some of the characteristics of war, such as violence. Moreover, the International



Encyclopedia of the Social and Behavioral Sciences defines terrorism as the “systematic use or threat of violence to communicate a political message, rather than defeat an opponent’s military forces” (Crenshaw, 2001, p. 15604). Therefore, war and terrorism have different connotations although they are often associated.

### **2.2.3. Defense Industry in Post-Cold War**

Political tensions during the Cold War had two main effects: first, they helped to settle certain conflicts; second, they limited the scope of the UN (United Nations) peacekeeping operations (Brune *et al.*, 2015). Nevertheless, the same authors also argue that the post-Cold War came to unblock this political impasse and resulted in a proliferation of conflicts and an expansion of the role of international organizations such as NATO (North Atlantic Treaty Organization) and the UN. Therefore, the end of the Cold War further stimulated research into the war’s declining trend (Sarkees *et al.*, 2003). This was much because of the widespread belief that war in the developed world is intolerably expensive, reckless, futile, and debased (McFaul, 2020; Mueller, 1990), but also because the bipolarity of the international system decreases its frequency and severity of war (Wayman, 1984). In other words, developed democracies are less likely to fight each other—known as the “democratic peace” theory (Dülffer, 2020; Kutz, 2016). However, this perspective is fully not consensual (Altman *et al.*, 2021), as other researchers note an increase in conflicts, particularly after the end of the Cold War. For instance, Mearsheimer (1990) argued early on that, if the Cold War ended, the war’s numbers would soon return to normal values; moreover, Kaldor (2012) identified new types of wars based on economic conflict and the activities of paramilitary actors. Finally, Huntington (2000) argued that ethnic conflicts will replace ideological, political, and economic ones.

Regarding the defense industry in the post-Cold War, Gregory (1993) argued early on that, with the decline of communism and fast victory in the Gulf, there were requests for defense budget cuts, reduction of military personnel, and cuts in technology, which led to a burden on the economy and huge reductions in research and development, harming the defense and commercial industries. Therefore, these may have been the first post-Cold War implications for the defense industry, being in line with the more general view of Wayman (1984) and Mueller (1990).

A more contemporary discussion seems to revolve around the convergence of the European Union (EU) with the USA reforms after the Cold War and in their “Revolution in



Military Affairs” or, alternatively, the convergence around its own revolution, in an attempt to emerge from the EU as a potential US military rival (Dyson, 2016; Raska, 2021). Despite the discussion around the Revolution of Military Affairs, little is known about how the nature of war influenced the defense industry in the post-Cold War and how it contributed to the stratification of political power, which we can understand in the findings section of this article.

### **2.3. Methodology**

This article builds on a systematic literature review (SLR) by following the preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol. The systematic review was selected since it aims to synthesize the existing body of completed and recorded work produced by researchers (Fink, 2020) in a “replicable, scientific and transparent” way (Tranfield *et al.*, 2003). This strategy is adequate as it allows one to discover concepts, ideas, and debates about the defense industry in the post-Cold War, providing the needed state-of-the-art and conceptual basis to answer the research questions. The alignment with the SLR was achieved through the PRISMA protocol (Table 3), which includes a checklist of 27 items and a four-phase flowchart that allows replicability and transparency (Moher *et al.*, 2009). Regarding the four-phase flowchart, we first identified relevant keywords (*e.g.*, “Defense Industry AND “Politics”) to identify the theoretical body of knowledge, which allowed us to understand the phenomenon (identification phase); then, the most appropriate manuscripts were determined through the application of pre-established filters (screening phase). Finally, the next phases focused on the accessibility criteria (eligibility phase) and the inclusion criteria of additional and relevant manuscripts (inclusion phase).



**Table 3** – Four phases of preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol

Scopus	n
Identification	
“Defense Industry” AND “Politics” (All)	1883
Screening	
Title, abstract and keywords (Title-Abs-Key)	45
Language (English)	43
Time (around 1989)	41
Eligibility	
Full-text manuscripts	41
Included	
Included studies	41

Source: Own authorship

The search was performed on 6 November 2020 and started with the inclusion of the keywords “Defense Industry” AND “Politics” in all fields, resulting in the identification of 1883 documents. For a more focused result string, we decided to narrow the search by screening the documents in “title, abstract, and keywords.” In addition, a second and a third filter were applied to sort manuscripts written in English, avoiding misinterpretation (Rosete *et al.*, 2020), and those published from 1989 onwards to contribute to the post-Cold War academic debate. After the screening phase, there were no further developments, as it was possible to access the full text, and no more relevant documents were included, resulting in a total of 41 manuscripts.

A true SLR generally uses several databases in an attempt to include a larger number of relevant manuscripts; however, we chose to use only one database because we appreciate transparency and ease of replicating the results, which is in agreement with other published articles (Reis *et al.*, 2019; Reis *et al.*, 2020b). Within a wide range of databases, Scopus Elsevier was selected since it combines a comprehensive, curated abstract and citation database with enriched data and linked scholarly content to quickly find relevant and trusted research (Scopus, 2020), but, foremost, it gives great emphasis on humanities and social sciences when compared with similar databases (*e.g.*, EBSCO, ScienceDirect, or Web of Science) (Harzing & Alakangas, 2016; Martín-Martín *et al.*, 2021), while it indexes a larger number of journals (Falagas *et al.*, 2008). Scopus presents less coverage when compared to a general purpose engine, such as Google Scholar, especially in humanities and social sciences; however, it covers peer-reviewed scientific documents, which are often associated with higher quality, but it provides advanced search and filtering functionalities (Martín-Martín *et al.*, 2021).



The results are twofold, as they are presented quantitatively and qualitatively. Firstly, the quantitative analysis followed the bibliometric method which was established as a scientific specialty (Ellegaard & Wallin, 2015). The bibliometric literature of this study was extracted from Scopus, grouping a series of graphs that were suggested by the database to allow a quick and visual analysis by the readers. Secondly, the content analysis technique (Bryman & Burgess, 2002) was used to identify, evaluate, and synthesize the existing body of knowledge. Thus, in the first phase, we read the 41 manuscripts to familiarize ourselves with the most relevant concepts (Jesson *et al.*, 2011); in the second phase, we codified similar terms to group them by clusters, namely, in categories and subcategories (Given, 2008); in a third phase, we classified those categories to identify patterns, reduce data, and make sense of the information (Petticrew & Roberts, 2008). To assist in this complex process, we used qualitative data analysis software—Nvivo 12 (Edhlund & McDougall, 2019).

Due to the theoretical nature of this research, the used information was publicly accessible and previously published, thus, it was not required to seek institutional ethics approval (Suri, 2020). Moreover, according to Suri (2020), the Institutional Review Boards for ethical conduct of research do not typically include guidelines for systematic reviews. The issue of ethics in systematic reviews is rarely addressed (Vergnes *et al.*, 2010). As systematic reviews are a synthesis of a multitude of information, an anti-plagiarism tool (Turnitin.com) was used (Wager & Wiffen, 2011) to enable the identification and validation of all the references used in this article. For quality and reliability purposes, the Turnitin report can be sent by email to interest parties.

## **2.4. Findings and Discussion**

This section provides a holistic, theoretical, and conceptual overview of the defense industry in the post-Cold War period. The analysis and the discussion of the results include two analyses, a quantitative (bibliometric) and a qualitative (content analysis), to answer the research questions and, at the same time, fill the literature gap.

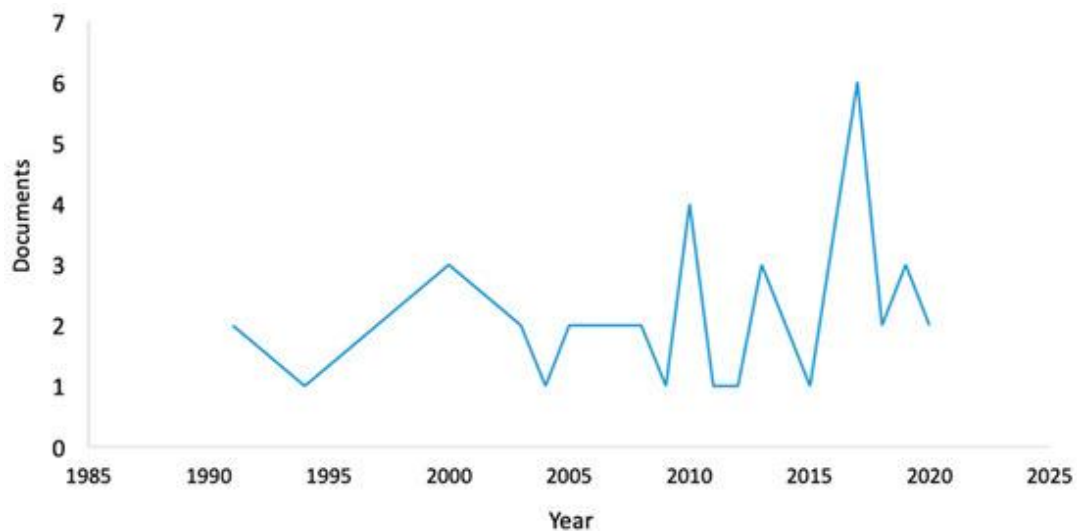
### **2.4.1. Quantitative Analysis**

The graphical analysis (Figure 5) highlights a significant peak in 2017 (*i.e.*, six articles). These publications are mainly associated with the European Defense, Technological and Industrial Base (EDTIB) (Maye, 2017), the European Defense Agency (EDA) (Calcara, 2017), and the EU Directive on intra-Community Transfers of Defense



Equipment (Fiott, 2017). These manuscripts show that cooperation and interdependence of the European defense industry are central to EU policy, essentially for security and economic reasons. Nevertheless, some EU Member States remain reluctant to acquire weapons at regional levels and not so much at national and international levels. On the other hand, the EU policy is encouraging the USA to respond with protectionist measures, as is argued later in this article.

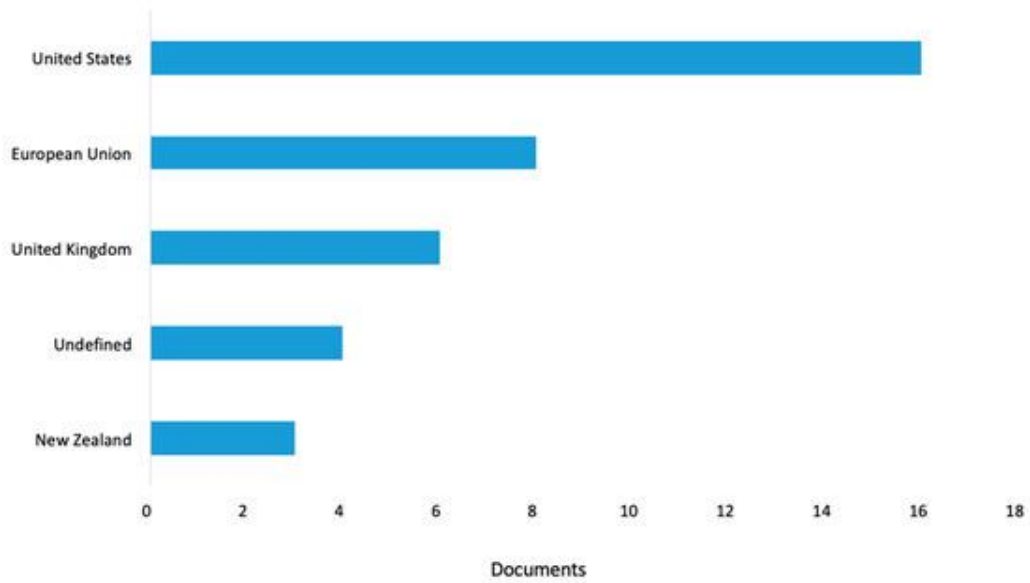
**Figure 5** – Documents by year



Source: Retrieved from Scopus database

To our surprise, the People’s Republic of China has no known publications (Figure 6), not because there are no developments in this country but due to the defense industry’s association with politics and, in this regard, there is some understandable protection of know-how, especially concerning political support for innovation and military development. In contrast, the USA, the EU, and the United Kingdom (UK) dominate the ranking, given that they clearly announced public measures to support the defense industries but also with special emphasis on the possible different approaches in which the defense industries position themselves in these countries. In the cases of the USA and the UK, they tend to move towards an autarky, while the EU’s defense policy and industry move the path of integration. From a political standpoint, it is interesting to see how the different strategies (*i.e.*, integration, autarky, and domination) allow the stratification of power and the consequent dynamics of growing conflict. Although the bibliometric section is more informative, we know that, given the number of articles published, the USA and the EU will provide the necessary knowledge to obtain conclusive answers to the research questions.

**Figure 6** – Documents by country or territory (top five countries/territories)

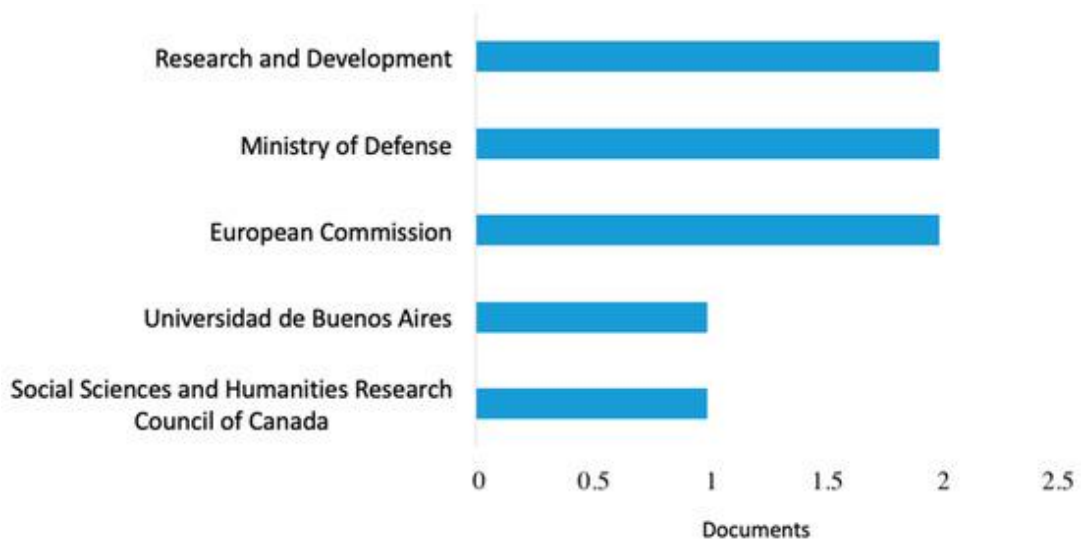


Source: Retrieved from Scopus database

The institutions that most financed scientific research were Argentina’s National Science and Technology Research Council and the European Defense Funds as well as the Ministries of Defense of Brazil and Argentina and, finally, the European Commission with structural Funds (Figure 7). In other words, it is easy to see that part of scientific funding comes from the European Union, although it is extremely scarce when compared to other areas of industrial research. In contrast, a quick search in Scopus with “defense industry” in Title-Abs-Key shows that the National Natural Science Foundation of China is the State research center that most funds scientific publications worldwide, demonstrating a clear political support for innovation and development of its defense industry.



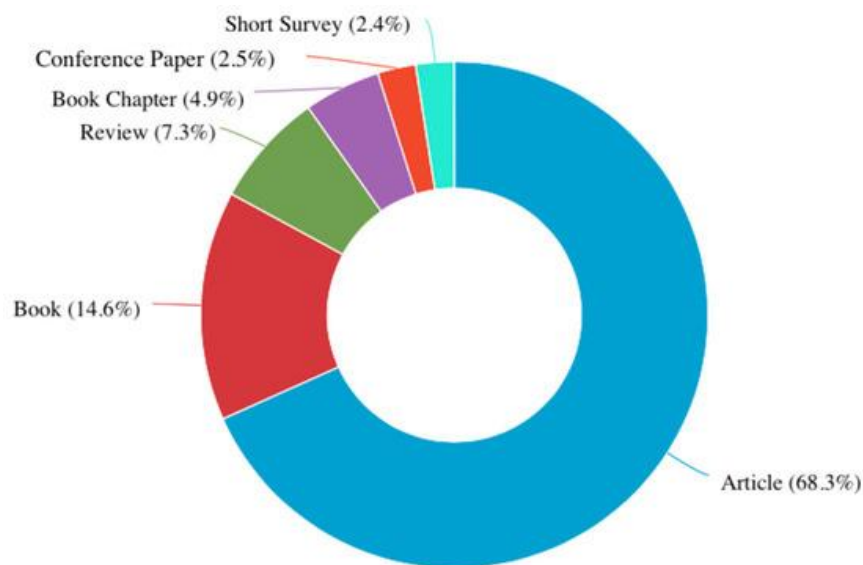
Figure 7 – Documents by funding sponsor (top five funding sponsors)



Source: Retrieved from Scopus database

Although funding for scientific research linking policy to the area of the defense industry is still very low, both at national and supranational levels, we found that most of the published documents are scientific articles (68.3%) from journals with a high impact factor (Figure 8). A more detailed analysis showed that 61% of the articles are placed in quartiles Q1/Q2 and 39% in quartiles Q3/Q4, which indicates the high quality of the scientific research in the context of the defense industry and the interest of editors/publishers in these areas.

Figure 8 – Documents by type

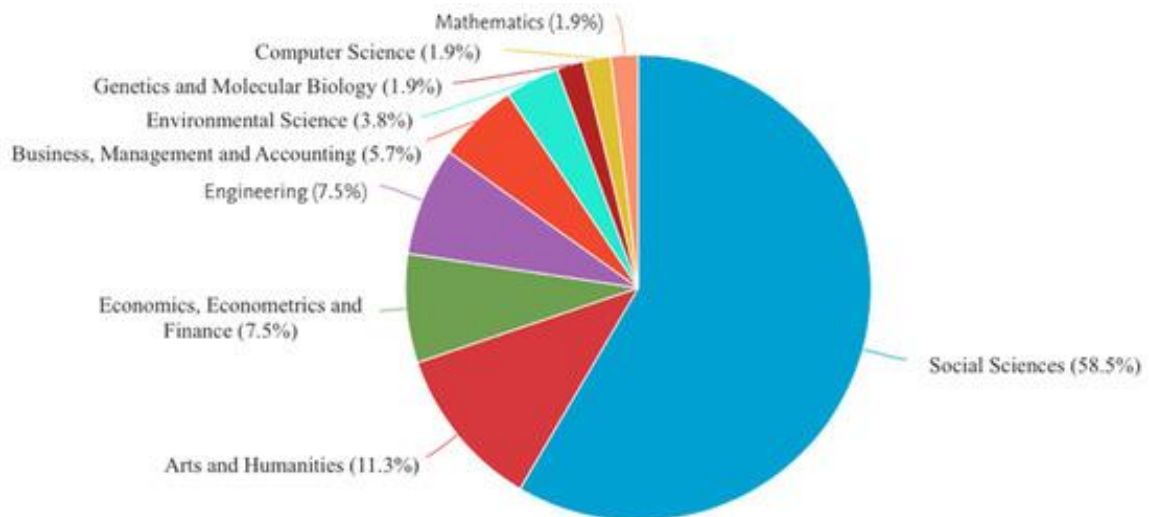


Source: Retrieved from Scopus database



Eventually, one would expect to find a strong connection to research in the context of industrial engineering and management, which is true if the search terms are “defense industry” in Title-Abs-Key. However, the data showed that a large part of the research (58.5%) was carried out within the scope of social sciences and arts and humanities (11.3%) (Figure 9). The results are inevitably related to the applied filter in Scopus, that is, “Politics”, and, therefore, most manuscripts are from the fields of political and military sciences. As we explore the relationship between the defense industry and social and political sciences, we see some interesting results, namely: (1) the contributions of the defense industry to society; and (2) a quadruple helix connection. Starting with the first contribution, Kurian (2000) stated that the technology-intensive defense industries of the People’s Republic of China assumed a crucial significance in the modernization of the economy when they became part of civil and military production. In other words, the defense industry had a greater social impact due to its dual military–civilian use, generating development in terms of biotechnology, information, and communication systems, to name just a few areas. According to the above finding, it seems evident that the greater the integration between the defense industry and civil society is, the greater the propensity for stability will be, responding to some extent to the RQ2.

Figure 9 – Documents by subject area



Source: Retrieved from Scopus database

To a certain extent, the People’s Liberation Army (PLA) has also endeavored to develop its national defense program in an attempt to bring civil society closer to the government (Kurian, 2000), universities (Genevaz, 2019) and, not least, from the defense industry in an approach known in the literature as “quadruple helix” network. Therefore,



although the term has never been made explicit in the 41 manuscripts, it is implied that the quadruple helix appears to be contributing to the emergence of a greater number of publications in the context of social and political sciences.

#### **2.4.2. Qualitative Analysis**

This section summarizes the existing body of knowledge and provides answers to the research questions to fill the identified gap in the literature and to provide inputs for practitioners in the field.

The manuscripts' analysis did not reveal evidence of how wars influence the defense industry but of the State's adaptation to the needs and the demands that currently operate in the pulled systems, *e.g.*, to produce only what is necessary. In other words, there is no direct relationship with the nature of wars but instead concerning the relationship with States and their investment intentions. For example, the 9/11 terrorist attacks led to US military intervention in Afghanistan and Iraq in the so-called "Global War on Terror", and this intervention has reinvigorated the defense industry worldwide with the annual defense budget of USA that approached \$700 billion and with annual profits that almost quadrupled (Maye, 2017). According to Maye (2017), after a decade of fighting in Afghanistan and the withdrawal of Iraq's responsibilities, in 2011, the defense industry slowed again.

Regarding the contributions of the defense industry to the stratification of political power in the international system, we identified three approaches—integration, autarky, and domination—that have been carried out with or without State support. The first case shows how the defense industry has sought survival through mergers, joint ventures, and alliances without or with limited State aid, which, at the same time, has allowed new growth opportunities to arise on the international scene (case of European Defense Industry). The second case shows the possibility of autarky systems where independence or self-sufficiency are sought in other industries and which, in most cases, count on significant State aid (case of Turkey). Finally, the third case presents one in which global or regional domination is sought through industrial and military diplomacy (cases of the People's Republic of China and the USA).

As mentioned earlier, the post-Cold War spread beliefs that war was unbearably expensive, reckless, futile, and degraded (Mueller, 1990). The systematic review evidenced this phenomenon through Pernica (2020), who stressed that, in the Czech Republic, the government linked a partnership to the Czech Defense and Security Industry Association



(DSIA) but, since its creation in 2000, the DSIA lost market position. Neither the decision of the political parties nor the governments were able to support the national defense industry due to the end of the conscription armed forces. Only a few national members of the DSIA were able to compete internationally with its cutting-edge products. There is, however, a dichotomy: (1) regarding the EU, which has been active in the field of international security and defense, the defense industries have been somewhat removed from the central power of Brussels. This distancing is because national defense industries have traditionally played a fundamental role in the survival of European nation-states, thus making them reluctant to share this “sovereign instrument” with the European Union (Barrinha, 2010); (2) but also about recent developments in the economic field, with a large number of acquisitions and mergers within the European defense industry (Maye, 2017) and European policies with a focus on EU integration and defense. Both of these strategies (mergers and policies) contributed to building new opportunities for defense and security industries (Kenny, 2006). To cite an example, the merger in 2000 of the German Daimler Chrysler Aerospace with the Spanish aeronautical company, Construcciones Aeronauticas SA, and later with the French Aerospatiale-Matra created the European Aeronautic Defense and Space Company (EADS), later called Airbus, the third largest aircraft company in the world (Maye, 2017). Thus, the coordination of European defense policy and arms procurement through the European Defense Industry (EDA) aims to make the defense industry better structured and organized, and, in theory, this would lead to long-term coordination, cooperation, and integration between member States (Kenny, 2006), not to mention the various benefits of collective action, such as gains in specialization for comparative advantage in the development of military technologies, economies of scale and scope in large-scale operations, etc. (Hartley, 2003).

In South America, Brazil seems to follow a very similar path by choosing to strengthen the defense industry to stimulate its deterrent capacity and project an image as regional leader, although its defense capacity has not yet been sufficiently developed to promote desired results and because its effectiveness depends on actions in other dimensions of power (Rezende *et al.*, 2018). According to Rezende *et al.* (2018), the restructuring of the defense industrial base seems far from successful in the development of sustainable companies and products. If, on the one hand, there is still a great dependence on industrial-based defense programs for government financing, on the other hand, most defense programs are still under development and, therefore, it is too early to realize their effects (*e.g.*, sale of KC-390



transport aircraft). Thus, Brazil has accepted the establishment of international partnerships, integrating its efforts in a global production chain to concentrate its limited resources in niche markets (Bitzinger, 2003).

A different scenario is that of the Turkish defense industries, which have significantly improved their production capacity since 1980, reaching a production level of 54% in 2011 and expecting to reach the defense industrial autarky in 2023 (Kurç, 2017). However, Kurç (2017) also states that the Turkish defense industry remains inefficient due to weak institutions and civil-military rivalry. Although foreign partnerships have accelerated the development of defense companies, they continue to suffer from weak investments in research and development.

In Asia, the People's Republic of China assumes itself as a player in international politics by assuming regional dominance and using arms transfers as an instrument of foreign policy. A clear example of this is the sale of arms from the People's Republic of China to countries such as Bangladesh, Iran, Myanmar, Pakistan, Sri Lanka, and Thailand, which aims to promote military diplomacy, extending its external influence by arming its neighbors and establishing strong military ties with them in an attempt to reduce India's influence (Sachar, 2004). The policy of the People's Republic of China is somewhat like the USA since its dominance of industrial defense systems globally imposes major restrictions on the political choices of most States; as we mentioned earlier, it includes other arms-producing countries that remain hostage as sales and advanced technologies remain dependent on the USA, which increases the latter's political influence. A very clear example is provided by Maye (2017), who argues that, while in the EU, regulated contracting rules are standardized across the European defense market, foreign defense companies operating in the USA are required to follow an ever-changing series of rules as well as protectionist purchasing practices. Thus, arms sales are not always a straightforward task, as is the case for Canada-Saudi Arabia military equipment. The dichotomy involves the subordination of Canadian foreign policy and international peace and security to commercial aspirations and the questionable importance of the Canadian defense industrial base that underpins the arguments in favor of the contract (Gutterman & Lane, 2017). If, on the one hand, Canada's involvement in the international arms market through this sale is seen as an increase in violence and corruption in the international arms trade (Gutterman & Lane, 2017), on the other hand, the sale contributes to the necessary self-sufficiency by encouraging the necessary military. Additionally, by promoting Canadian national security (Perry, 2016), it



also serves as an important milestone that places Canada as a global player in the international arms trade. Thus, the commercial activity of the defense industry can develop greater or lesser acceptance depending on the internal political system of each State.

In short, while some countries are reducing their spending on the military industry, others still see this sector as an instrument of national sovereignty, strengthening it through acquisitions and mergers, seeking greater integration, and establishing long-term relations, as has been the case of the European Union. Thus, the EU is a remarkable case of integration and stabilization (Besch, 2019) with limited power stratification and, therefore, it is unlikely to become a catalyst for war or conflict. On the other hand, power becomes domination when it is articulated in stable and lasting structures of control of one agent or set of agents over another (Scott, 2007). To reach the stage of domination, it is often necessary to promote government-funded programs so that the defense industry strengthens itself to leverage its States to become players in the international arena. The most notable case of domination is the People's Republic of China, which seeks to assume regional dominance through military diplomacy in strengthening military relations with its regional partners to weaken its opponents. In that regard, the Chinese defense industry allows the stratification of regional political actors according to the degree of importance that the People's Republic of China attributes to them. If, under certain circumstances, the stratification of power cannot induce regional conflict, at the very least, it can cause instability in the international context (Zhang, 2020). An example of the aforementioned argument is the South China Sea (SCS) disputes, although there is still no consensus that the People's Republic of China is succeeding in military and geostrategic domains (Castro, 2020; Pasandideh, 2021). The evidence leads us to believe that the different strategies enable an increasing stratification of power (*e.g.*, integration < autarky < domination) and consequent increase in the dynamics of the conflict. In other words, if, on the one hand, we find examples of integration and stabilization (*e.g.*, EU case), on the other hand, domination is more subject to stratification and consequent political–military instability (*e.g.*, People's Republic of China). A more cautious approach to the phenomenon shows that there is no clear relationship between the defense industry as a catalyst for wars; the importance of its influence in strengthening military relations between States is evident, enabling those with greater industrial power to become players in the regional and international political system.



## **2.5. Conclusions**

This article examines the defense industries in the post-Cold War period and presents two important research questions. The first question investigates how the nature of war influences the defense industry in the post-Cold War period, while the second question focuses on how the industrial defense sector can contribute to the stratification of political power in the international system, either as a stabilizer or a catalyst for war and conflict.

To better organize the conclusion, this section discusses the theoretical and practical implications of the research, presenting the key study findings. Moreover, it presents the research limitations and how the researchers mitigated its effects. Finally, some recommendations for future studies are revealed.

### **2.5.1. Contributions to Theory**

This research presents several key findings. First, the existing literature does not reveal evidence about the nature of war and the evolution of the defense industry in the post-Cold War, however, concerning to the relationship with States and their intentions to invest, there is a clear link. Second, we find that the defense industry contributes to the stratification of political power since it can be used as an instrument of international policy or as a means of national sovereignty. In this regard, we identified three distinct approaches to the defense industry—integration, autarky, and domination. The integration is related to acquisitions and mergers between several defense companies to establish long-term relationships to obtain specialization gains and gains of scale, among other benefits. In the scope of autarky, the defense industries seek independence or self-sufficiency about other industries, counting in most cases with significant help from the State. In the situation of domination, the defense industry is used by the State as a political instrument to obtain gains in power or influence in the international political system. Third, the defense industry and its relationship with politics, conflicts, and war have increasingly aroused the interest of the academic community, as evidenced by the quality of scientific publications from PRISMA. The number of scientific publications is closely related to the evolution of the political relationship between the State and the defense industry, as it is through politics that innovation and development programs as well as industrial production are financed.



### **2.5.2. Contributions to Practice**

Regarding the managerial contributions, this article reveals possible relationships to be explored regarding the quadruple helix model, where close relationships are established not only between the defense industry and the government but also between universities and civil society. In addition, as we mentioned earlier, there are several approaches in the defense industry (*i.e.*, integration, autarky, and domination); the previous classification can serve as a guide for defense industrial managers and policymakers on the existence of various approaches that can eventually be explored in the long run. From the policy perspective, it may be interesting to understand how the different strategies (*i.e.*, integration, autarky, and domination) increasingly allow the stratification of power and the consequent dynamics of growing conflict. The results made it possible to establish a relationship between integration and stabilization, whose domination is close to stratification and consequent political-military instability.

### **2.5.3. Research Limitations**

The results of this research have known limitations for the use of systematic literature reviews. When using a scientific database, it is known that it is constantly updated with new peer-reviewed research, therefore, our sample presents a snapshot in time. By restricting research to the post-Cold War period, we at first excluded manuscripts that could be relevant but, for reasons of rigor, defined the time string to better delimit our object of study, which increased the probability of obtaining more accurate results. The selected keywords can also present different results, however, after having performed several simulations with synonymous words, we found that the keywords used in this study were the ones with the highest number of search results. Recognizing the mentioned limitations, we still believe in the value of this systematic review, as it presents the state-of-the-art of the defense industry in the post-Cold War in a few pages at the same time as it stimulates the discussion for future empirical studies.



#### **2.5.4. Recommendations for Future Research**

Future studies may focus on empirical research to validate the theoretical findings or to provide suitable rebuttals for the comments presented in this research. Possible empirical research would be to find the variables that lead some defense industries to seek synergies with each other (integration), resorting to mergers and acquisitions, while others prefer to seek State funds (autarky). Other empirical research may include an understanding of how to promote closer relations between the defense industry and States. In this context, the possibility of applying concepts developed by the production industry to the defense sector, such as servitization models, should not be disregarded. As far as we know, the orientation towards service-based business models allows for closer commercial relations with the States, in contrast to the product-orientated ones; however, little is known about this possibility in the scope of the defense industry and, therefore, further studies are needed.



### 3. Chapter III – High-Tech Defense Industries: Developing Autonomous Intelligent Systems (ID2)

#### Executive Summary<sup>2</sup>

Continuing from the first article, this second piece focuses on the momentum that the defense industries are gaining, as new technologies such as robotics and AI enable the development of highly innovative and disruptive autonomous intelligent systems. As far as we know, technological innovation operates on short innovation cycles, and thus, despite the potential of military technologies, there are lingering uncertainties regarding the allocation of limited financial resources to drive high-tech defense industries. To shed light on this matter, we decided to conduct a SLR using the PRISMA statement and content analysis. Our findings indicate that autonomous intelligent systems are being developed by the defense industry and categorized into three distinct modes—fully autonomous operations, semi-autonomous operations, and intelligent autonomous decision-making. Furthermore, it is essential to note that at the strategic level of warfare, there is limited room for full automation due to the necessity of human intervention. However, at the tactical level of warfare, there is a significant likelihood of industrial defense growth, as this level involves structured decision-making and complex analytical-cognitive tasks. In the execution of these decisions and tasks, robotics and AI can provide a substantial contribution surpassing human capabilities. Therefore, when building upon the preceding article, it becomes evident that the EU's defense industry integration approach will likely be geared towards tactical operations. With the release of the EU Strategic Compass for Security and Defense – EEAS in early 2022, it has come to our attention that EU leaders have identified space and cyber domains as strategically significant. This could provide an opportunity for us to expand our analysis in the future. Regarding the EU capabilities, our analysis of the strategic compass suggests that the EU needs to be more ambitious and coordinated in maintaining its competitive advantage and promoting technological sovereignty, especially in the domain of autonomous

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<sup>2</sup> This executive summary serves as an expanded version of the initially published abstract, providing a comprehensive understanding and ensuring alignment among the thesis articles. For citation guidance, please refer to the APA standards. For chapter citation: Reis, J., Cohen, Y., Melão, N., Costa, J., & Jorge, D. (2021). High-tech defense industries: Developing autonomous intelligent systems. *Applied Sciences*, 11(11), 4920. <https://doi.org/10.3390/app11114920>. For thesis citation: Reis, J. (2023). Development of an N-Helix Innovation Model for the Portuguese Defense Industry. Military University Institute. Portuguese Ministry of Defense.



systems and digital technologies. Examples include remotely piloted aircraft systems, with a particular focus on research and development of defense algorithms and detection capabilities in mobile robots to enhance situational awareness. However, guidelines for the military and non-military use of AI have been somewhat underdeveloped by the European Parliament, which emphasizes that 1) AI should not replace human decision-making or human contact, 2) the EU strategy should prohibit necessary autonomous lethal weapon systems, and 3) calls for the prohibition of "highly intrusive social scoring applications" by public authorities (European Parliament, 2021). AI should, therefore, remain subject to human control, allowing humans to correct or deactivate it in the event of unexpected behavior. Nevertheless, there are reports of inconsistency between the European Commission's position on excluding military AI from its emerging AI policy and simultaneous EU political initiatives aimed at supporting military and defense AI elements at the EU level (Lingevicius, 2023). Furthermore, the significance of AI has grown considerably to date (September 2023), as AI-based technology supplied by the European industry stands as one of Ukraine's key assets against Russia—unmanned aerial vehicles (supplied by the USA, Norway, Luxembourg, and the UK) and autonomous underwater drones (supplied by the Netherlands) have been tasked with preventing Russian attacks (Fanni, 2021). According to the EDA, there is already a structured dialogue among EU member states regarding the development and use of AI in defense. The EDA has been working on developing a shared perspective on AI capabilities since 2016. It has coordinated various research and development projects addressing AI, including the creation of a common definition, taxonomy, and glossary for AI to address potential conceptual differences among states, a shared vision of relevant application areas for the European Capability Development Plan within the broad spectrum of AI-enabled capabilities, and an action plan for EU collaboration on AI in defense, which was slated to be presented to the EU Defense Minister in December 2020 (Boulanin *et al.*, 2020). However, these documents have not yet been made public. Because of that, we have not extensively delved into the AI issue, although we acknowledge its significance. Hence, while we refer to AI, the technologies explored in this thesis do not encompass any AI components, except for issues related to military drones, which, although possessing such capabilities, have not been extensively explored. The lack of information on the topic and political-legal ambiguity has thus far precluded an in-depth doctoral thesis study. In summary, the overarching trend appears to be that the level of cooperation and integration of advanced military technologies



will determine whether Europeans have the means to independently pursue common security objectives. The EU should strengthen its technological and industrial base, including, an enhanced common EU approach to emerging and disruptive technologies in the field of security and defense. Moreover, the EU should also promote a coherent, long-term approach to these matters, such as increasing investments in military technologies, ensuring synergies among civil, military, and space industries, and exploring possibilities for cooperation with NATO.

**Keywords:** artificial intelligence; defense industry; high technology; intelligent systems; level of war; robotics

### 3.1. Introduction

Advances in intelligent defense systems are growing and paving the way for high technological defense industries. Technologies such as robotics (Ha *et al.*, 2019; Lin *et al.*, 2021), artificial intelligence (Mori, 2018), and the Internet of Things (IoT) (Mariani *et al.*, 2021) are driving considerable changes and impacts on defense industries (Payal *et al.*, 2021). These technologies are known to be capable of developing autonomous intelligent systems, increasingly designed for military applications, and capable of operating efficiently in conflict areas and war zones. Thus, technology is often considered to be the key to many military revolutions in history, the so-called major military innovations or, as others have named, radical change in military affairs (Rossiter, 2020a). Three main factors are driving the latest revolution in military affairs: (1) rapid technological advancements that moved the Industrial Age into the Information Age; (2) the end of the Cold War; and (3) the decline in United States defense budgets (Tilford, 2021).

In recent years, we have identified several studies on the development of autonomous defense systems in the industry sector. Some examples are presented by Zhang *et al.* (2017), who focus on studying autonomous defense systems and relevant technological applications (*e.g.*, X47-B, Predator, Global Hawk). However, apart from the division of warfare applications to the best of our knowledge, no article has so far made a characterization of the autonomous defense systems literature in modes. That said, our intention is to explore and understand the following two research questions:

Research Question 1. How can the several modes of autonomous defense systems in the defense industry be categorized?



Research Question 2. How does the characterization of the autonomous defense systems modes contribute to making the defense industry highly technological?

Considering these research questions, it is quite evident that this research aims to understand and describe a real-life phenomenon, as suggested by Yin (2018). Although the research is of a qualitative and descriptive nature, it falls within the domain of applied sciences since it aims to identify the existing gaps and fill these gaps by initiating new scientific research in robotics and artificial intelligence applications at the various levels of war. It would seem, thus, inappropriate to carry out a more in-depth study to improve the high-tech defense industry without first knowing the holistic view of the use of autonomous defense systems.

This topic is important since there has been an exponential investment in autonomous intelligent systems in the military sector (Payal *et al.*, 2021). However, to the best of our knowledge, there has been no prior characterization of the modes of operations of these systems. In that regard, our article provides a comprehensive characterization of autonomous intelligent systems according to the various levels of war and different types of decisions and artificial intelligence. In addition to presenting a characterization of the various modes of autonomous intelligent systems in the defense industry, this article also characterizes how these modes contribute to making the defense industry highly technological. The novelty of this article is associated with the need to increase the degree of intelligent automation at the lowest levels of war. The need for automation is justified by the argument that, at the tactical/operational level, the military follows clear orders and makes structured decisions. Therefore, if structured decisions are made at the tactical level, which requires the performance of tasks of an analytical-cognitive nature, the type of intelligence needed is mechanical, thus, justifying the replacement of military personnel by machines, creating an excellent opportunity for the technological defense industries. On the other hand, at the strategic level of war, there is limited scope for the use of lethal autonomous weapon systems, given the need for human intervention, so as not to run into the current United Nations ethical, moral, and legal guidelines. Thus, this article's specific strengths are also associated with the managerial contribution, insofar as it provides the due knowledge on where to invest innovation and development resources of intelligent autonomous technologies, where they have a more significant growth perspective (*i.e.*, in field operations—tactical level).



The remaining of the paper is organized as follows: the next section presents a conceptualization of the most relevant terms and applications; this is followed by an explanation of the methodological process; the results of this study are presented in Section 4, where the answers to the research questions can be found; in the last section, the conclusions are withdrawn, focusing on theoretical and managerial contributions, research gaps and suggestions for future work.

### **3.2. Conceptual Background**

This section presents a brief conceptualization of the most relevant terms for this research. It also discusses the challenges for the defense industry and analyses the applications of autonomous intelligent systems in war.

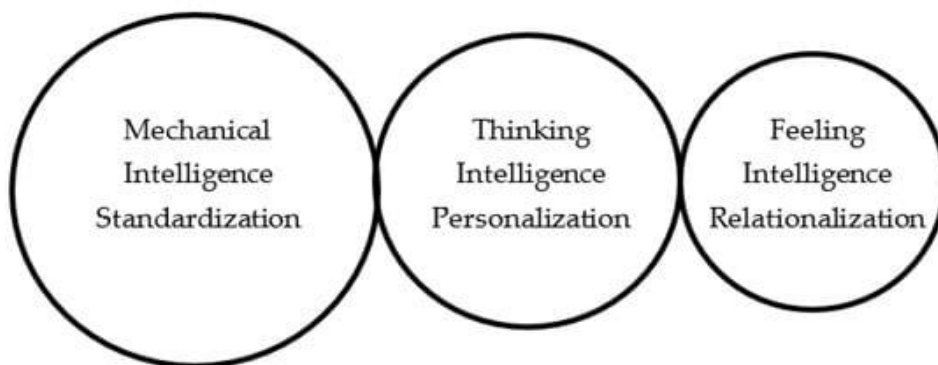
#### **3.2.1. Concepts and Definitions**

In recent years, one of the most profound changes in the defense sector has been the use of robots, aiming to replace human beings in tasks of high precision and analytical-cognitive complexity (Chamola *et al.*, 2021), tasks of high risk for human life (Šipoš & Gleich, 2020) and/or physically and physiologically strenuous (Simon, 2015; Walsh & Low, 2021). To that end, the defense industry developed various sophisticated warfare applications that can operate in multiple domains (*i.e.*, space, cyberspace, air, sea, and land). Due to a wide range of defense technologies, it is currently difficult, if virtually impossible, to describe consensual warfare applications among all defense researchers and academics. In addition to the growing demand for autonomous defense systems, a relevant argument that justifies the writing of this article is the degree of maturity that some military technologies have achieved (Rossiter, 2020b). The degree of maturity is somewhat related to the high learning curve of autonomous defense systems, due to the increased connectivity of these systems, via remote and network connection (*e.g.*, fifth-generation technology standard for broadband cellular networks—5G) (Garg *et al.*, 2021; Rathje & Katila, 2021) and easy access to big data. Those characteristics allow autonomous defense systems to make decisions quickly, without empathetic or emotional impasses, which is an important distinctive characteristic when compared to human beings (Reis *et al.*, 2020b; Rosete *et al.*, 2020). Thus, autonomous defense systems work without human interference, boosted by the latest advances in intelligence, cognition, computing, and system sciences (Wang *et al.*, 2020). When referring to autonomous defense systems, most are robots that detect, identify,

understand, and interact autonomously with the external environment. Their capacity is based essentially on three functionalities: (1) sensors, which detect the environmental characteristics (Horowitz *et al.*, 2019); (2) artificial intelligence, which identifies and understands the surrounding reality (Horowitz *et al.*, 2019); and (3) mechanisms, which allow real interaction (Sandin, 2003).

Several articles in the literature carried out an analysis of automation, autonomy, and intelligence, which allows us to understand the most relevant terms. For instance, Insaurralde and Lane (2014) define automation as the ability of a system to automatically carry out a certain process by following a code. They define autonomy as the ability of a system to carry out an automatic process by making decisions, implementing the choices made, and checking the evolution of such actions, *i.e.*, making choices on its own. On the other hand, the human intelligence literature usually defines intelligence as the human ability to learn over time and adapt to the external environment (Schlinger, 2003; Sternberg, 1999). Moreover, the artificial intelligence literature states that intelligence is the capacity to mimic human intelligence (Huang & Rust, 2018), such as the ability of knowledge and reasoning (Leidner, 2019), problem-solving (Ibarz *et al.*, 2021), communicating, interacting, and learning (Richards & Matuszek, 2021). Huang and Rust (2018) and Huang *et al.* (2019) also proposed three artificial intelligences—mechanical, thinking, and feeling (Figure 10).

Figure 10 – Three artificial intelligences



Source: Adapted from Huang & Rust (2018)

Mechanical artificial intelligence is used for simple, standardized, repetitive, and routine tasks. An example of a civil application of mechanical intelligence is the use of service robots to clean hotel rooms, replacing humans in routine and standardized tasks (Rosete *et al.*, 2020). Thinking artificial intelligence is used for complex, systematic, rule-based, and well-defined tasks. An example of this is Boston Dynamics' quadrupedal robots,



highly adaptable, versatile, and capable of capturing the mobility, autonomy, and speed of living creatures (Murphy *et al.*, 2011; Raibert *et al.*, 2008). Feeling artificial intelligence is used for social, emotional, communicative, and interactive tasks (Huang & Rust, 2021, p. 32). Due to limited empathic and socioemotional capacity of machines, we believe that feeling artificial intelligence in the military domain should be performed by human beings. This argument is justified by the current state of social and emotional evolution of intelligent machines, which has not yet reached the desirable stage. For instance, it is difficult to imagine a lethal autonomous weapon system (Taylor, 2021) in a combat situation with socioemotional ability capable of deciding whether to kill a child with a weapon in his possession. Such complex and socioemotional tasks require skills that are currently at the limit of the human being; some activities can eventually be shared with intelligent machines, but in the context of the decision-making process. We will hardly see a robot crying for a human in its current stage of evolution, whereas the opposite is already true. For example, when Boomer “died” in Iraq, the American soldiers offer him an impromptu military funeral—in this case Boomer was not a human being, but a robot whose job was to search for and defuse bombs (Nyholm & Smids, 2020). Perhaps due to examples such as this one, robots have been increasingly integrated and accepted into military teams (Bellás *et al.*, 2020).

It is likely that the types of intelligence are also related to the types of decisions, as we will see in the Results section. Laudon and Laudon (2014) classified decisions as structured, semi-structured, and unstructured. According to these authors, unstructured decisions are those in which decision-makers must evaluate and decide about something that is new, not routine, and for which there is no previously defined procedure. These decisions are made at the strategic level of the organization. In contrast, structured decisions are repetitive and routine, where established rules and accepted procedures are previously defined. Decisions of this type are taken at the operational management level. Intermediate decisions are semi-structured, where only part of the problem has a clear answer defined by a well-accepted procedure.

### **3.2.2. Type and Levels of Autonomy**

The type and levels of autonomy are also well described in the literature, although the measurement scales are not always consensual, making it difficult to select a model. In that regard, Vagia *et al.* (2016) presented a literature review of the evolution of the levels of



autonomy since the end of the 1950s (Table 4).

**Table 4** – A taxonomy for the levels of autonomy

<b>Levels of Automation</b>	<b>Description</b>
Level 1—Manual control.	The computer offers no assistance.
Level 2—Decision proposal stage.	The computer offers some decision to the operator. The operator is responsible for deciding and executing.
Level 3—Human decision select stage.	The human selects one decision, and the computer executes.
Level 4—Computer decision stage.	The computer selects one decision and executes with human approval.
Level 5—Computer execution and on human information stage.	The computer executes the selected decision and informs the human.
Level 6—Computer execution and on-call human information stage.	The computer executes the selected decision and informs the human only if asked.
Level 7—Computer execution and voluntary information stage.	The computer executes the selected decision and informs the human only if it decides to.
Level 8—Autonomous control stage.	The computer does everything without human notification, except if an error that is not into the specifications occurs. In that case, the computer needs to inform the operator.

Source: Adapted from Vagia *et al.* (2016)

One of the most interesting aspects we highlight in (Table 4) is the introduction of the failure mode at the fully autonomous control stage (level 8), which means the computer operates completely autonomously unless an unexpected error occurs. If the error does not appear in the program specifications, the computer must seek human support. This human support is relevant to the subject of this paper since, at the limit of the use of military technologies, there may be a need to attack human beings without any margin of error in selecting those who live or die. The intervention of human beings was not frequently considered at this level, as observed in one of the most relevant studies about levels of autonomy, published by Endsley and Kaber (1999). The taxonomy of Vagia *et al.* (2016) intends to combine a series of levels from other articles that seem to have no significant differences between them, presenting the reader with a simpler and easier-to-understand model. The authors also intended to present a taxonomy that could be widely used, and, in this regard, the authors stated that it is up to the user to decide how to create their own taxonomy at the automation level and prioritize their needs and requirements. The modes of autonomous intelligent systems that we further developed show some similarities with the



model of Vagia *et al.* (2016), although it is not as comprehensive as it focuses on a specific domain (*i.e.*, military field).

### 3.2.3. Military Applications and Autonomous Intelligent Systems

The defense industry is increasingly conducting autonomous defense systems research and development in several domains: space, cyberspace, air, sea, and land. It is in that regard that we present an overview of military application of autonomous defense systems in each of the mentioned domains:

- Space robotics and autonomous intelligent systems.
- Autonomous intelligent cyber-defense agents.
- Intelligent unmanned autonomous systems—in the air, at sea, and on land.

Space robotics autonomous intelligent systems are presented as machines capable of operating in space and carrying out exploration in adverse environments that may not be found in the natural conditions of the Earth. In general, space robots are divided into two types: (1) orbital robots (Giordano *et al.*, 2020), which are characterized by robotics in low earth orbit or robotics in geostationary orbit; and (2) planetary robots (Sancho-Pradel & Gao, 2010), which are capable of closely examining extraterrestrial surfaces. As mentioned by Gao *et al.* (2021), depending on the applications (orbital or planetary), space robots are often designed to be mobile, manipulate, grab, drill, and/or collect samples, such as the National Aeronautics and Space Administration's recent Mars 2021 Perseverance Rover (Voosen, 2021). These robots are expected to have several levels of autonomy, from teleoperation by humans to fully autonomous operations. Depending on the level of autonomy, a space robot can act as (Gao *et al.*, 2021): (1) a robotic agent (or human proxy) that can perform teleoperation up to semi-autonomous operations; (2) a robotic assistant, who can help human astronauts that range from semi- to fully-autonomous operations; or (3) a robotic explorer capable of exploring unknown territory in space using fully autonomous operations. As an exemplary method, Giordano *et al.* (2020) is presented as a validating benchmark. They reported an efficient fuel control strategy for a spacecraft equipped with a manipulator. Their key findings are associated with the strategy of using the thrusters, the reaction wheels, and the arm drives in a coordinated way to limit the use of the thrusters and achieve the ideal zero fuel consumption in non-contact maneuvers. The authors were able to validate the method via a hardware-in-the-loop simulator composed of a seven-degrees-of-freedom arm mounted on a simulated six-degrees-of-freedom spacecraft. Some military space robotics



autonomous intelligent systems are related to spy satellites of some military powers and space-based missile defense systems.

Autonomous cyber defense is an area that has been driven by the defense sector in anticipation of threats to military infrastructures, systems, and operations (Theron & Kott, 2019). These systems will be implemented through autonomous and intelligent cyber-defense agents that will fight against intelligent autonomous malware (Theron & Kott, 2019) and are likely to become primary cyber fighters on the future battlefield (Kott, 2018).

The popularity of advanced applications in the domains of air, land, and sea has also been steadily increasing (Campbell *et al.*, 2012) with the intelligent unmanned autonomous systems, which can perform operations without human intervention with the help of artificial intelligence (Zhang *et al.*, 2017). In that regard, intelligent unmanned aircraft systems have aimed at autonomous flight, navigation, sensory, and decision-making capabilities (Santoso *et al.*, 2018) above conventional unmanned aircraft systems or unmanned aerial vehicles. Currently, unmanned aircraft systems and unmanned aerial vehicles systems have often been used for intelligence, surveillance, and reconnaissance activities or to carry out attack missions against high-value targets (Udeanu *et al.*, 2016). In addition, several methodologies have been targeted to these systems, such as Jourdan *et al.* (2010), who designed an approach to mitigate common unmanned aerial vehicle failures, including primary control surface damage, airframe damage, and complete engine failure. Intelligent unmanned aircraft systems are beginning to be developed mainly in the civil context, such as package delivery (Stolaroff *et al.*, 2018), agriculture, and agroindustry (Hartanto *et al.*, 2019), to name a few. The intelligent unmanned maritime and underwater systems have pushed the technology beyond imaginable limits in order to deal with complex ocean and sea missions (Insaurralde & Lane, 2014). These systems present new opportunities for naval use, in particular for dangerous missions, such as highly efficient mines sweeping. Recognizing the potential of autonomous underwater vehicles for both science and the military, in 1997 the Massachusetts Institute of Technology and the North Atlantic Treaty Organization joined efforts to develop robotic technologies applicable to mine countermeasures (Bovio *et al.*, 2006). These systems have evolved with the use of disruptive technologies until today (Bistrion & Piotrowski, 2021). For example, Sands (2020) developed very relevant methodologies in this regard. He studied deterministic artificial intelligence for unmanned underwater vehicles, proposing an automated control and learning methodology that requires simple user inputs. Noteworthy is also the attention that has been given to unmanned ground



vehicles. Of these, an interesting example is the BigDog, developed by Boston Dynamics, which is a four-legged robot for transporting loads in difficult terrain (Campbell *et al.*, 2012) and has been adapted with autonomous navigation (Wooden *et al.*, 2010). Moreover, mathematical structures and expectation-maximization and Gaussian mixture models algorithms have been developed (Bistrion & Piotrowski, 2021). Besides its applications in robotics and unmanned ground vehicles, these algorithms can also be used in various domains such as cybersecurity, object detection, and military logistics. The practical application of these algorithms has resulted in modern technology that can be applied on the battlefield, as presented by Bistrion and Piotrowski (2021), who give us examples of solutions such as Spot and Atlas (also developed by Boston Dynamics). In addition to the potential for civil society, much is speculated about the use of these autonomous robots in the revolution of military ground operations (Rossiter, 2020a).

### 3.3. Methodology

This study was carried out as a systematic literature review, based on the original guidelines proposed by Moher *et al.* (2009). This research strategy is well justified by Fink (2020), who argues that it is: systematic, since it embraces a methodological approach; explicit, as all data collection procedures are described in it; and comprehensive, as it brings together a wide range of scientific knowledge. The search process was undertaken in Elsevier's Scopus, one of the World's largest abstract and citation databases of peer-reviewed literature. By choosing Scopus over other scientific databases (*e.g.*, Web of Science, EBSCO Host, ScienceDirect) and/or academic search engines (*e.g.*, Google Scholar), this article takes advantage of (1) greater transparency and easy replicability of results (Tranfield *et al.*, 2003), (2) superior coverage of journals in the fields of applied and technological sciences (Reis *et al.*, 2021a), (3) peer-reviewed articles, which increases the quality of the results and the credibility of the research, (4) wider application of filters, and (5) immediate generation of search results in graphs and tables. Thus, based on the previous advantages, the use of a single scientific database has been accepted by the academic community (Reis *et al.*, 2021b). By following the assumptions of Moher *et al.* (2009), this research uses the PRISMA Statement (also known as Preferred Reporting Item for Systematic Reviews and Meta-Analysis), which consists of a 27-item checklist and a four-phase flow diagram. The checklist includes items considered essential for the transparent reporting of a systematic review (Liberati *et al.*, 2009). As Page *et al.* (2021) points out, each



item on the checklist was accompanied by an “explanation and elaboration”, providing additional pedagogical justifications and guidance for each item, along with examples to demonstrate complete reports. The adoption of the guideline has been extensive, as indicated by its citation in tens of thousands of systematic reviews and frequent use as a tool to assess the integrity of published systematic review reports (Page & Moher, 2017). To do so, the search was initially conducted on 14 April 2021, by identifying documents with the terms “Defense Industry” and “Intelligent Systems” in all fields of search.

Following the typical application of filters during the screening phase of the PRISMA protocol, manuscripts were selected by source type, document type, and language (Table 5). The screening phase allowed more accurate results to be obtained. The selection of the source and type of document is closely related to the quality of the publication, as there seems to be a consensus among the academic community that journal articles are those that generally have superior scientific quality. Moreover, the option of selecting articles in English seemed to be an adequate option to avoid misinterpretations of the articles; on the other hand, as English is used worldwide, it involved a greater article coverage when compared to any other language. Following, the eligibility phase allowed to exclude articles that were not strictly related to the topic; and the inclusion criteria, which allowed to add manuscripts that were relevant to corroborate some information retrieved from Scopus. The final sample consisted of 62 articles from peer-reviewed journals (Table 5). The data analysis followed the technique known as content analysis (Flick *et al.*, 2004; Neuendorf & Kumar, 2016) to highlight new concepts and ideas (Krippendorff, 2018). The first phase started with the reading of all articles to identify similar words and terms (Stemler, 2000). After grouping the text, we identified the most relevant categories and subcategories (Elo & Kyngäs, 2008). In the next phase, we hierarchized the categories and subcategories to identify the patterns and ideas (Hsieh & Shannon, 2005). To assist in the analysis, we used a qualitative data analysis software—NVivo 11 (Bazeley & Jackson, 2019), whose process allowed to obtain a holistic view of the existing literature, which is presented in the next chapter.



**Table 5** – Scopus search with PRISMA statement

Elsevier’s Scopus® Database	<i>n</i>
<b>Identification</b>	
“Defense Industry” AND “Intelligent Systems” (All fields)	153
<b>Screening</b>	
Source type (Journals)	67
Document type (Articles)	61
Language (English)	57
<b>Eligibility</b>	
Full-text articles assessed for eligibility	51
<b>Included</b>	
Included studies (+11 articles)	62

Source: Own authorship

### 3.4. Results

Since early, Hetrick (1996) defined the high-tech defense in four manufacturing industries. The first two manufacturing industries are known as the aerospace industry—aircraft, guided missiles, and space vehicles; the third is the ordinance and accessories, and the fourth corresponds to navigation systems and equipment manufacturing. All these industries can operate in the development of autonomous defense systems. One example is the research on ammunitions in future intelligent combat, which is a timely topic (Liu *et al.*, 2021). After carefully evaluating the applications of autonomous defense systems, it is safe to argue that three generic modes can be identified in the defense industry.

#### *Three Modes of Autonomous Intelligent Systems in the Defense Industry*

We identified high-technological autonomous defense systems that are being developed by the defense industry, and that can be categorized into three different modes (Table 6). The proposal to categorize autonomous defense systems modes is due to the scarcity of scientific production that favors a taxonomy for this type of system, both autonomous and intelligent. Given the above, we continue by answering both research questions through real-life examples, considering the challenges and opportunities of each modality.



**Table 6** – Modes of autonomous intelligent systems in the defense industry

<b>Modes of Autonomous Intelligent Systems</b>	<b>Description</b>	<b>Levels of War</b>	<b>Decisions Type</b>	<b>Types of Artificial Intelligence</b>
Mode 1–Fully autonomous operation	The human has no control over the operation	Military tactical	Structured decision	Mechanical intelligence
Mode 2–Partially autonomous operation	The human has some kind of control over the operation, or the system assists humans and vice-versa	Military operational	Semi-structured decisions	Thinking intelligence
Mode 3– Smart autonomous decision-making	The intelligent system supports humans in case of need	Military strategic	Unstructured decisions	Feeling intelligence

Source: Own authorship

- Mode 1. Fully autonomous operation (the human has no control over the operation).

The doctrine of war is normally divided into three levels—strategic, operational, and tactical (Kiszely, 2005; MacGregor, 1992). The first mode of autonomous defense systems usually operates at the tactical level, as it requires structured decisions in the field of operations. While the Mode 1 has greater efficiency when compared to humans, humans are expected to be replaced by machines in the middle and long term. Considering the previous argument, Mode 1 is expected to strongly contribute to make the defense industry highly technological. At lower levels of war (*i.e.*, tactical level), structured decisions are made since soldiers are limited to following well-defined orders on the battlefield. In these situations, the performance of tasks is of an analytical-cognitive nature, where mechanical intelligence is the most recommended; that is, machines must take control of military operations. One example of Mode 1 from the data collected from Scopus is given by Rossiter (2020a), who recently published an article on the use of unmanned ground vehicles and how they are revolutionizing ground military operations. Rossiter (2020a) corroborates our previous arguments in the extant that unmanned ground vehicles’ use has been intensified in recent years due to artificial intelligence, advanced computing, sensors, vision systems, and propulsion technologies. Rossiter (2020a) also refers that the United States Autonomous Systems Strategy (published in 2017) defined as a medium-term priority (2021–2030) the need to have fully autonomous unmanned combat vehicle operations. However, when it comes to the use of unmanned ground vehicles, recent history has shown that technological developments are promising but, so far, are unsatisfactory due to the created expectations. Thus, expectations have been made that there will be machines that will completely replace humans on the battlefield, but the defense industry is far from achieving that goal. In short,



as can be seen in Table 6, fully autonomous operations (Mode 1) operate at the level of tactical warfare where structured decisions are made and which, in turn, refer to a type of mechanical intelligence. As far as mechanical intelligence is concerned, humans are likely to start losing control of these military operations to machines. Building upon the previous arguments, the next natural step is to define the construction elements of different types of weapons, as suggested by Božanić *et al.* (2020), in order to produce autonomous systems suitable for users.

- Mode 2. Partially autonomous operation (the human has some kind of control over the operation, or the system assists humans and vice-versa).

Mode 2 is suitable for the operational level of warfare, as humans generally need to make semi-structured decisions with a medium level of responsibility. In this case, machines are recommended to take control over military operations, albeit with some kind of human control. An example of Mode 2 was also obtained from Scopus. In a first stage, it was possible to ascertain that in the context of the naval defense situation, awareness of the battle space is mission critical. According to Dalkıran *et al.* (2021), in platform-centered warfare, each combat unit keeps an individual situational awareness that is limited by a geographical area due to the limited range of the sensors (*e.g.*, radar, optical and infrared sensors, sonar). The authors also refer that it is possible to achieve a shared battlefield awareness by connecting combat management systems on warships with command-and-control systems. Therefore, they proposed a communication mechanism for integrating data distribution service systems in real-time, where a combat management system could support military personnel on a warship with two main functions: (1) creating awareness of the battle space in real-time; (2) eliminating enemy forces using onboard weapon systems. According to Dalkıran *et al.* (2021) research, a combat management system generates a tactical image with tracking data from various sensors and using data fusion algorithms. Subsequently, the collected information is sent to the weapon systems at high frequencies to engage enemy forces. These systems are generally used at an operational and strategic level, helping commanders to accomplish the security mission. Briefly, and as can be seen in Table 6, military operations are partially autonomous. These are carried out at the operational level of war and where semi-structured decisions are made. These levels/decisions result in the domain of thinking intelligence, as mentioned by Huang *et al.* (2018, 2019). This type of intelligence applies to complex tasks based on well-defined rules. Therefore, it is likely that



humans will also lose some control of these military operations to the machines or to models which support decision-making (Božanić *et al.*, 2019; Božanić, Tešić, *et al.*, 2020; Malbašić & Đurić, 2019). Typically, artificial intelligence algorithms are used to simulate the human analytical, cognitive, and intuitive components.

- Mode 3. Smart autonomous decision-making (the intelligent system supports human decision).

Mode 3 is suitable for strategic military operations, as humans are usually required to take complex and unstructured decisions with a high level of responsibility. In that regard, autonomous defense systems advise and support the human decision-making process, but do not replace humans in their decision. As these advanced systems are intelligent and autonomous, the upper limit of their military use can result in serious injury or loss of human life's, which means that, at a strategic level of war, it may be advisable to maintain some degree of human intervention and decision-making, preventing machines from killing humans indiscriminately in case of error. Furthermore, whereas in the manufacturing and services industry some degree of automation may be acceptable at high levels of decision, in the military and defense industry this is highly discouraged. So, it is necessary to find ways that allow the development of intelligent machines without coming up against the current ethical, moral, and legal guidelines of the United Nations (UN) (Arkin, 2018; Righetti *et al.*, 2018). These guidelines emphasize responsibility in deciding by humans over machines to safeguard interest in preserving human life. Given the above, it is likely that there will be little room for automation in Mode 3, which will not contribute to the same extent as Mode 1 to make the defense industry highly technological. From the content analysis, we can verify a relevant finding associated with the diversity of the degree of performance of the autonomous defense systems at the strategic level. That is, the autonomous defense systems that operate at the strategic level, mostly also operate at the lowest levels of the war. An example of the previous argument is unmanned aerial vehicles, which, due to their exponential growth and wide variety, can be used at all levels of war. The range of performance of unmanned aerial vehicles is discussed by Hamurcu & Eren (2020) when they argue that they can be piloted remotely or fly autonomously or semi-autonomously. Their variety is mainly due to technological advances in robotics, which can imply widespread use, ranging from surveillance, tactical reconnaissance, and combat operations. If within the scope of surveillance and reconnaissance it can be acceptable for



unmanned aerial vehicles to be autonomous and intelligent, regarding combat operations, there has been much resistance in automating their decision.

Table 6 summarizes all the information regarding the autonomous defense systems Modes in the defense industry. Below we present the section of conclusions that focus on the main contributions of this research.

### 3.5. Conclusions

The purpose of this article was twofold. It first presented a characterization of the various modes of autonomous intelligent systems in the defense industry. Then, it characterized how those modes contribute to making the defense industry highly technological.

The results indicate that the autonomous intelligent systems can be categorized in three different modes—fully autonomous operations, partially autonomous operations, and intelligent autonomous decision-making. Regarding Mode 1, since autonomous defense systems perform complex analytical-cognitive operations more efficiently than humans, it is likely that the latter will be replaced by machines in the medium and long term. Mode 2 is recommended to be run by autonomous defense systems, while humans can assume some kind of control. At this level, operational missions are developed, where human beings are called upon to make semi-structured decisions. Finally, at a strategic level, autonomous defense systems support humans in case of need. Therefore, in this specific case, autonomous defense systems only support but do not replace humans in its decision. Each mode contributes differently to making the defense industry highly technological. In other words, from our analysis, we conclude that it is likely that automation in Mode 3 will be much more limited when compared to Mode 1. This is because in Mode 3 there must be a higher degree of decision and human intervention, which surpasses the previous modes that should have a higher degree of automation. These results provide guidance on the levels of automation where defense managers must invest their time and resources in research and development. So, scientific research in military technologies is recommended to focus on the first two levels of war (*i.e.*, Tactical and Operational). As for the strategic level, the technological application is still very limited in the domain of empathic capacity in decision making, so it will likely continue to be operated in the hands of humans.

As this article follows a systematic literature review, some limitations are worth mentioning. First, the research presents a snapshot of the reality. Indeed, the Scopus database



is constantly being updated, and, thus, some relevant research has likely been left out of the analysis. Second, other articles may be left out of the analysis due to the application of filters. However, the PRISMA protocol allows the inclusion of relevant articles, mitigating the effects of that exclusion. Third, if different keywords are selected on Scopus, the search may also yield different results. However, after having performed several simulations with synonymous words, we found that the keywords chosen were those with the largest number of search results. Finally, the results have not been empirically tested and validated. Despite the mentioned limitations, the analysis of the existing literature allowed the presentation of a holistic view of the phenomenon, which is focused on the autonomous defense systems in the context of defense, but also provides managerial guidelines on where to invest the resources. Following this article, we suggest empirically testing and validating the findings to analyze if the research and development in the defense industry is moving in the right way. A second study can be focused on the technological transfer to the production industry and its commercialization, given that many of the existing theoretical studies end up not being carried out in practice. Finally, it may be interesting to study complementary fields of research for intelligent autonomous systems. This is the case of notable researchers such as Kwon *et al.* (2019, 2020) who bring us neural network applications and adversarial examples. These military applications allow to deception of enemy classifiers, and to safeguard the tactical use of intelligent autonomous systems.



## **4. Chapter IV – Defense Industries and Open Innovation: Ways to Increase Military Capabilities of the Portuguese Ground Forces (ID3)**

### **Executive Summary<sup>3</sup>**

After a thorough examination of the second article, which revealed a likelihood of industrial defense growth at the tactical level of warfare, our focus now shifts to an in-depth analysis of military equipment developed by the Portuguese consortium known as "Auxdefence." As we embark on this new chapter, it becomes evident that the industrial landscape is operating within a quintuple-helix innovation model, with robust engagement from universities and governments in pushing innovation forward. Moreover, the exciting dimension emerges that military innovations are progressively making their way into civilian society, accompanied by a growing emphasis on environmental considerations. Beyond substantiating the presence of technological advancements within the tactical sphere of warfare, we have also recognized a striking fact: the defense sector stands as one of the most important consumers of energy resources. Amid this revelation, the European defense industry, despite the aspirations of select EU nations, remains a substantial contributor to environmental challenges. Fiott (2014), a preeminent think-tank specializing in strategy and defense affairs, offers a compelling perspective on how ecological endeavors within the European defense sector are attributed to diverse stakeholders: Military Personnel – they are actively involved in environmental audits, both during and after military operations, ensuring accountability for environmental impact. Defense Companies – these entities invest significantly in technological innovations, not only to enhance military capabilities but also to streamline logistical and production processes, thus promoting efficiency and sustainability. Governments – through the enactment of European and national regulatory and legislative measures, governments play an important role in shaping the environmental trajectory of the defense sector. In addition to our state-of-the-art analysis, employing the

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<sup>3</sup> This executive summary serves as an expanded version of the initially published abstract, providing a comprehensive understanding and ensuring alignment among the thesis articles. For citation guidance, please refer to the APA standards. For chapter citation: Reis, J., Melão, N., Costa, J., & Pernica, B. (2022). Defense industries and open innovation: ways to increase military capabilities of the portuguese ground forces. *Defense Studies*, 22(3), 354-377. <https://doi.org/10.1080/14702436.2022.2033117>. For thesis citation: Reis, J. (2023). Development of an N-Helix Innovation Model for the Portuguese Defense Industry. Military University Institute. Portuguese Ministry of Defense.



PRISMA technique, we present an illustrative case study involving the Portuguese Defense Industry. This case study draws from a multitude of data sources, selected to ensure triangulation and corroboration, thereby enhancing the robustness of our findings. In summary, our results underscore the transformative potential of the quintuple-helix innovation model, enabling the seamless translation of theoretical concepts into tangible real-world applications. Furthermore, situated within the framework of the triple-helix model, we have successfully conceived, manufactured, and field-tested military products tailored for tactical deployment, bolstering the combat readiness of ground forces. While the environmental dimension remains an unexplored terrain in this chapter, we defer its comprehensive analysis to the forthcoming chapters of this thesis. This decision allows us to explore deeply the environmental sustainability within the defense industry, offering a holistic understanding of its evolving landscape.

**Keywords:** defense industry; open innovation; ground military forces; quintuple helix

#### 4.1. Introduction

Open Innovation (OI) is currently at the center of academic debate. This phenomenon is identified by several scholars, who argue that it is not uncommon to find articles referring to OI and its ability to integrate internal and external knowledge into companies' value chain (Brunswick & Vanhaverbeke, 2015; Rogo *et al.*, 2014). In this regard, Chesbrough (2003) mentioned that OI started when organizations realized they could not solely rely on their own research and development capacities. This situation triggered the adoption of an innovation approach focused on collaboration with external stakeholders to share knowledge, resources, and technologies Randhawa *et al.* (2016).

The scarcity of published articles on OI in the defense industry is well evidenced in the largest databases of peer-reviewed literature. To support our argument, on May 9 we conducted a quick search on Scopus (Elsevier), which resulted in six documents with the search terms "open innovation" AND "defense industry" in the title-abstract-keywords. Thus, very few studies like this one have been identified. Worthy of note is the Triple Helix (TH) approach Etzkowitz and Leydesdorff (1995, 2000) used by the Brazilian Army (Fernandes *et al.*, 2020), which stimulated innovation between the Army, the defense industry, and the academy. Similar research was conducted in Portugal with a paper that analyses the relationship (*i.e.*, TH) within the defense industry to determine how the



university-government-industry relationship works (Simões *et al.*, 2020). A few existing studies analyze the adoption of the TH model and OI by the defense industry, but none have studied other recent typologies. For example, the Quadruple Helix incorporates the TH (university-industry-government) while adding the “public based on media and culture” and “civil society” Carayannis and Campbell (2012, 2009). Moreover, the Quintuple Helix (QH) innovation model is more holistic and incorporates the “natural environments of society” (Carayannis & Campbell, 2010). Our paper addresses this gap, specifically understanding if the defense industry and OI allow the establishment of innovative dynamics in the light of the QH; Within the defense industry, we focus on the Army, given the increasing military capabilities of ground forces (Fernandes *et al.*, 2020).

To fill that gap in the literature, the objective of this research is twofold. Our first objective was to understand a phenomenon that has been little studied and for which little is known (Yin, 2018); to do so, we used a Systematic Literature Review (SLR) to collect and analyze the most relevant data. The second objective was to describe the phenomenon in its natural setting; to do so, we conducted one case study research to corroborate the results from the literature and find novel insights. That said, we developed two research questions (RQ), as follows:

RQ1: How is OI improving the defense industry and increasing military capabilities?

RQ2: How is the QH innovation model energizing the military capabilities of ground forces?

The first research question is central, as this study focuses on open innovation in defense industries. Furthermore, we identified the need to define a second research question to discuss a more focused topic and deepen the research, analyzing, in that regard, the military land resources in the light of the quintuple helix. For a better understanding, we also divided this article into five sections. We started with an introduction to the topic, and in the next section, we discussed the most relevant concepts, which will be helpful for the results and discussion section. The third section presents the research design and is subdivided into two parts: the first focuses on explaining the SLR; the second focuses on the case study research. The fourth section reports the results and discussion of this research. Finally, we present the conclusions, which focus on the contributions to literature and management practice, the limitations, and perspectives for future research.



## **4.2. Conceptual Background**

This section addresses relevant concepts, whereas the theoretical framework will be discussed in-depth in the results section.

### **4.2.1. European Union (EU) Defense Industry**

The priority of European Defense lies in the level of evolutionary ambition through the Common Security and Defense Policy (CSDP) and in the revolutionary impulse through European Defense Funds (EDF). The CSDP enables the European Union (EU) to meet its crisis management responsibilities and act as a global security actor, taking a leading role in peacekeeping operations and conflict prevention operations (EEAS, 2021a). While, the European External Action Service (EEAS) is the EU's diplomatic service that manages the EU's relations with other countries outside the bloc and conducts EU foreign and security policy (EEAS, 2021b). Moreover, in the EU, the Directorate-General for Defense Industry and Space (DG DEFIS) leads the activities of the European Commission in the defense industry and space sector, being in charge of upholding the competitiveness and innovation of the European defense industry (DEFIS, 2021). Some key actions and priorities of the DG DEFIS are: 1) to implement and oversight the European Defense Fund (EDF), which is one of the European Commission's main initiatives supporting research and the development of defense capabilities (for 2021–2027) (EU Space Policy); and 2) to build an open and competitive European defense equipment market and enforcing EU procurement rules on defense.

Regarding the EU defense industry, a relevant episode may be identified in mid-2004, as a defense structure was created under a Joint Action of the EU Council of Ministers, called the European Defense Agency (EDA) (EDA, 2021a). This agency promotes, supports, and integrates the EU member states in improving the European defense capabilities within the EU's CSDP. In 2016, the European Commission proposed the European Defense Action Plan (EDAP), intended to increase the research and development capabilities of the EU defense industry and promote the investment in the EU's Defense Technological and Industrial Base (EDTIB) (DGNDP, 2021a). One year later, in 2017, the 25 EU Member States ratified the intention of launching a Permanent Structured Cooperation (PESCO) and, in the same year, the first research grant agreement, directly funded by the EU is signed. Moreover, the EDA and the EEAS together form the Secretariat of the PESCO, which serves as a platform, and where PESCO participating Member States nations can “identify, assess



and consolidate” projects to make sure they respond to the Capability Development Plan (CDP) (EDA, 2021b). The CDP is produced by EDA (in cooperation with the EU Military Committee (EUMC) and the European Union Military Staff (EUMS)) to address long-term security and defense challenges, making recommendations about the EU military capabilities over time, including future scenarios (EDA, 2021c). The CDP is of particular importance, as it served as a baseline for the implementation of major EU defense initiatives launched following the 2016 EU Global Strategy – as the CARD (Coordinated Annual Review on Defense), the PESCO, and the EDF. The most tangible output of the 2018 CDP revision is the eleven new EU Capability Development Priorities in fields such as cyber response operations, ground combat capabilities, air mobility, among others (EDA, 2021c).

If in one hand, it is a symbol of the EU’s commitment in trying to create a solid and integrated Pan-European defense industry (EP, 2020); on the other hand, efforts to integrate the EDTIB also take risks, as the EU can be seen as protectionist, which can lead other significant arms suppliers, such as the United States of America (USA), to pay back in the same coin (Reis, 2021).

#### **4.2.2. EU ground combat forces**

One of the main priorities of the 2018 CDP Revision is the development of Ground Combat Forces Capabilities. The 46 PESCO undergoing projects cover 1) training areas, as well as the 2) terrestrial, 3) maritime, 4) air and 5) cyber environments, and 6) joint enablers (PESCO, 2020). Of these projects, 1/5 has more than seven members, of which France, Italy, Spain, and Germany are the most involved ones, while almost half have only three or fewer participants (Nádudvari *et al.*, 2020). Despite the high involvement of the EU Member States in the areas of PESCO capacity, the EU ambition, and the revised CRP for 2018 are more comprehensive. Regarding the EU Ground Combat Forces, it is anticipated that they will operate in environments of high threat intensity, and face technically advanced adversaries. To that end, the CRP defined priority areas for land combat a wide range of resources, as identified in Table 7.



**Table 7** – CRP priority in land combat and corresponding PESCO Project

<b>CRP Priority in Land Combat</b>	<b>Current PESCO Project</b>
1. Current and future armoured land platforms ( <i>e.g.</i> , Infantry fighting vehicles and armoured personnel carriers)	Armoured Infantry Fighting Vehicle/Amphibious Assault Vehicle/Light Armoured Vehicle (AIFV/AAV/LAV)
2. Next generation of ground-based precision strike capabilities ( <i>e.g.</i> , indirect fire support and anti-tank weapons)	Indirect Fire Support Capability (EuroArtillery)
3. Unmanned ground combat capabilities to improve force protection in the domains of Counter Improved Explosive Devices (C-IED), Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) capabilities, and Personnel Recovery techniques	Integrated Unmanned Ground System (UGS) Deployable Military Disaster Relief Capability Package (DM-DRCP)
4. Individual soldier equipment	No project associated with this CRP Priority has been identified

Source: Adapted from CDP (2019) and PESCO (2020)

Some criticisms are also worth noticing as the vast majority of EU Level of Ambition (LoA) shortfall areas are currently not covered by PESCO projects (Billon-Galland & Efstathiou, 2019). According to Billon-Galland and Efstathiou (2019), PESCO has the potential to become relevant if EU Member States show a willingness to go beyond political and industrial obstacles. It is in this respect that the QH is suitable since PESCO alone should not have a significant impact on the fulfilment of the entire EU CSDP.

We have not identified any PESCO project in one of the CRP areas of Ground Combat Forces (*i.e.*, individual equipment). However, we noted that some EU member states have been conducting research and development (R&D) activities independently, in collaboration with various national entities. In this context, Portugal can be a relevant player, as it has been carrying out R&D in this area of activity in the light of the QH Innovation Model. In turn, this indicates that eventually this country may be preparing to lead actions in this field of research, particularly in the context of PESCO, in partnership with other European states.

#### **4.2.3. Open Innovation and the Quintuple Helix Innovation Model**

Since the mid-2000s, innovation ecosystems have been gaining relevance in emerging industries (Arenal *et al.*, 2020). The literature has evolved into several models of N-helix, gravitating around stakeholders, internationalisation, specialisation and ecological

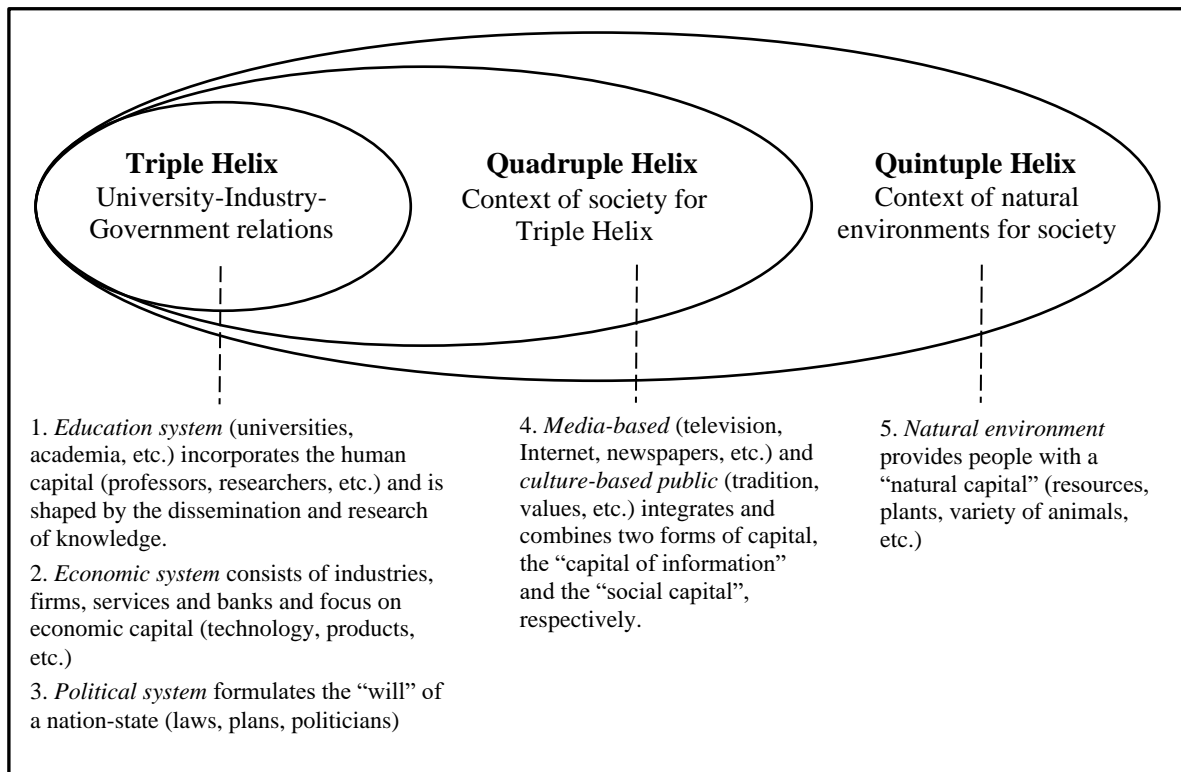


conservation (Lew & Park, 2021), which offers several opportunities to study these models in the light of various industrial sectors. As previously mentioned, the QH innovation model is based on the Triple and Quadruple Helix models, adding the “natural environment” to the fifth helix (Figure 11). The QH model combines knowledge, know-how, and the natural environment system in an “interdisciplinary” and “transdisciplinary” structure, as it involves an analytical understanding of the five helices and requires the continuous involvement of the entire disciplinary spectrum as a coherent whole (Carayannis & Campbell, 2010; Choi & Pak, 2006).

Wars are so intense that they have the potential to alter the biosphere. Therefore, it is acceptable to argue that contemporary military activity can change the function of ecosystems with highly adverse effects. These effects cause dramatic changes in habitat through environmental pollution, population declines, and losses of biodiversity due to acute and chronic effects on both terrestrial and aquatic systems (Lawrence *et al.*, 2015). Examples of these negative changes are associated with contaminants, nuclear radiation, effects of low-precision weapons, etc. However, according to Lawrence *et al.* (2015), in specific war situations, such as “exclusion zones,” it can generate beneficial conditions, protecting the fauna and flora.



Figure 11 – Triple-, Quadruple-, and quintuple-helix innovation models and their subsystems



Source: Adapted from Carayannis and Campbell (2012)

Regarding the QH’s natural environment, it is quite normal for critics to question ecological conservation in the military context. This argument is supported by the perception that environmental harm during a war is generally accepted as an inevitable form of collateral damage (Marler, 2013). In contrast, civil society is unwilling to accept environmental damage resulting from military operations (Marler & Moore, 2011). Therefore, advancing the ecology of war is a scientific and moral obligation (Machlis & Hanson, 2011). Thus, there is a need to counterbalance the intensity of the destructive impacts of war and the reduction of ecosystem and human life degradation.

### 4.3. Methodology

This research is qualitative, exploratory, and multimethod. Its multimethod nature is explained by the combination of several methods of data gathering and data analysis from two methodological traditions (Seawright, 2016). In other words, multimethod studies assume the use of qualitative or quantitative techniques in the same research (Mills *et al.*, 2010), with the intention of understanding and describe a phenomenon for which little is known (Yin, 2018). Thus, this article includes two qualitative research strategies, namely a systematic literature review (Petticrew & Roberts, 2008; Torgerson, 2003) and a single case



study research (Yin, 2018). Both strategies have the intention of complementing each other (Reis *et al.*, 2020c), as the SLR provides the conceptual basis from a “replicable, scientific and transparent” process (Tranfield *et al.*, 2003, p. 209), and the case study aims to support, explore and explain a reality (Gerring, 2006).

### 4.3.1. Systematic Literature Review

The SLR was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) by Moher *et al.* (2009). As shown in Table 8, in the identification phase, we analysed the entire scope of the research using appropriate keywords. Then, the screening phase filtered documents according to quality (journals) and comprehension (language) criteria. Next, the eligibility is related to accessibility and inclusion of relevant documents not previously identified in the Scopus database.

The search was carried out on March 9<sup>th</sup>, 2021. The use of Scopus is justified by its broad coverage of peer-reviewed literature, multidisciplinary, ability to apply filters, and the easy retrieval of bibliometric data. The coverage selection considered the analysis and pre-test of a series of databases, such as the Web of Science, B-On, and EBSCO. Academic search engines, such as Google Scholar, were initially excluded because they include non-peer-reviewed literature and have a limited scope for applying filters. In addition, Scopus also emphasises the human and social sciences compared to similar databases (Martín-Martín *et al.*, 2021), and has been used in similar research (Reis, 2021).

Table 8 – Four phases of PRISMA protocol

Elsevier’s Scopus® Database	n
<b>Identification</b>	
“Defense Industry” AND “Innovation” (All)	25,909
<b>Screening</b>	
Title, abstract, and keywords (Title-Abs-Key)	198
Journal (Articles)	99
Language (English)	80
<b>Eligibility</b>	
Repeated articles removed	79
<b>Included</b>	
Included studies (+1 article)	80

Source: Own authorship

We started the SLR with the identification criteria, using the terms “defense industry” AND “innovation” in all search fields. The search fields were then filtered by “title, abstract and keywords.” The screening criteria also included articles from Journals, as they are



generally of better quality, although we know that some relevant articles may have been excluded. To increase comprehension, we selected documents in English; otherwise, we could have interpretation bias. We decided not to include any time restrictions so as to have a broader understanding of the literature. The process continued until the duplicate articles were excluded (due to a database error). Finally, we have included an article about the defense industry within the scope of the triple helix in Portugal. After applying the PRISMA protocol, the result was 80 peer-reviewed articles.

#### **4.3.2. Case design**

This research has the portuguese defense industry (idD – Portugal Defense) as a unit of analysis. Its centrality is justified by the geographical position of Portugal as the most western country of Europe, enhancing the trans-Atlantic relations of the EU and their American allies. As a founding member of the North Atlantic Treaty Organization (NATO), member of the EU, and member of the Eurozone, Portugal is a relevant entry point to the centre of Europe. Moreover, Portugal is also a key player in the Community of Portuguese Speaking Countries (CPLP), bridging South America (Brazil), Africa (Angola, Mozambique, Cape Verde, São Tomé and Príncipe, Guinea-Bissau, and Guinea Equatorial), and Southeast Asia (Democratic Republic of Timor-Leste).

The idD carries out the sectorial defense policy by consolidating a public business decision centre (idD, 2021). IdD intends to leverage financial instruments, both national and European, to create value within the framework of the European defense policy. Thus, it promotes, develops, and supports the organisations that integrate the Portuguese Defense Technological and Industrial Base (DTIB) in coordination with the Directorate- General for National Defense Resources (DGNDR). The latter State agency (DGNDR) develops and coordinates the national defense policies for human resources, materials, and infrastructures (DGNDR, 2021b). In turn, the DTIB is composed of public or private organisations operating in the defense and security sectors. These organisations are mainly composed of SMEs (Small and Medium-size Enterprises) organised by clusters (Table 9).



**Table 9** – Portuguese defense technological and industrial base

<b>Cluster</b>	<b>Quantity of Companies</b>
1. Aeronautic	30
2. Communications and Information Systems	57
3. Construction and Engineering	31
4. Cybersecurity	8
5. Energies	12
6. Environment	13
7. Footwear	6
8. Goods and Catering	6
9. Health	7
10. Land	5
11. Naval	19
12. Organizations	18
13. Research	26
14. Robotics and Automation	8
15. Security	29
16. Services	26
17. Technological Materials	37
18. Textile	24
19. Transports	12
20. Unmanned Aerial Vehicles (UAV)–Unmanned Underwater Vehicles (UUV)–Unmanned Ground Vehicles (UGV)	8

Source: Adapted from DTIB (2019)

Overall, DTIB brings together more than 380 public and private SMEs active in Research and Technological Development (RTD). Despite their arrangement in clusters, it is typical for organisations belonging to different clusters to cooperate with each other, seeking synergies, which is seen as an advantage.

To achieve the proposed objectives and adequately answer the research questions, this case study collects data from several sources, namely in-depth semi-structured interviews, participant observation (*i.e.*, webinars<sup>4</sup>, seminars<sup>5</sup>, workshops, and focus groups<sup>6</sup>), and official documents. The semi-structured interviews incorporated open questions to enable

<sup>4</sup> Webinars and workshops were organized by the: a) idD – Portugal Defense; b) Auxdefence – Advanced Materials for Defense Seminars; c) Portuguese Military Academy.

<sup>5</sup> Seminars were organized by the: a) Portuguese Presidency of the Council of the European Union; b) Auxdefence – Advanced Materials for Defense Seminars; c) Portuguese Military Academy.

<sup>6</sup> Focus groups were organized following the seminars and workshops with the experts in the field.



participants to narrate their experiences (Galletta, 2013). However, the focus of the questions was deliberately and carefully linked to the research theme through a protocol designed for this purpose (Castillo-Montoya, 2016). The interviews were conducted via video call via Colibri/Zoom, allowing the researcher to develop the conversation. After the meeting, the recording was transcribed verbatim and sent to the participants for validation. In cases where the answers were not so clear, we returned to respondents to collect more data, resorting for that purpose to a digital whiteboard tool (Miro's online Mind Map). Miro whiteboard enabled brainstorming and allowed to map processes online until a deeper comprehension of the phenomenon was achieved. The respondents were selected using convenience and snowball sampling (Merriam & Tisdell, 2015). Although guidelines for determining non-probabilistic sample sizes are practically non-existent (Guest *et al.*, 2006), we stopped collecting data when we reached theoretical saturation. That is, the interviews were carried out to “the point where no more could be added” (Costley & Fulton, 2018, p. 178). Overall, we conducted 17 in-depth interviews. This number is within the range typically suggested in the literature, which generally points to 15–25 interviews to obtain a rich understanding of the phenomenon under study (Hennink *et al.*, 2017; Marshall *et al.*, 2013; Saunders & Townsend, 2016).

Regarding participant observation, the researchers assumed an active role in the event (Mills *et al.*, 2010). Therefore, the researchers were directly involved in webinars and seminars; through networking, focus groups were also carried out. Although participant observation did not offer direct data on the broader context of those being observed (Berg, 2004; Lune & Berg, 2017), it allowed for establishing purposeful interactions to collect data for corroboration and triangulation purposes. After the workshops were held, we brought together a relatively small group of participants to enable brainstorming and allow everyone to get involved in the discussion. The focus groups proved to be very relevant, as they made it possible to gather groups of experts who participated in the workshops and who were highly involved in the idD – Portugal Defense.

This article also includes a third source of data collection, consisting of organisational documents (Given, 2008) retrieved from the official websites of the idD – Portugal Defense, the Portuguese Defense Technological and Industrial Base (DTIB), and the Directorate-General for National Defense Resources (DGNDR). Regarding the ethical guidelines, a document was presented to the participants with relevant and detailed information about the research. Moreover, a signed and informed consent form (including consent for audio



recording) was obtained and documented in the light of the Declaration of Helsinki (2013). The data were analysed using thematic analysis techniques (Sundler *et al.*, 2019) and content analysis (Krippendorff, 2018; Vaismoradi *et al.*, 2013), with the aid of computer-assisted data analysis software (CAQDAS) called NVIVO – QSR International (Version 11) (Neuendorf & Kumar, 2016; Woolf & Silver, 2017). We started by classifying the most relevant phrases and ideas, followed by the coding process and text interpretation (Gibbs, 2012). As coding requires substantial effort, creativity and self-reflection (Drisko & Maschi, 2016), we opted for two coding approaches – deductive and inductive. In the thematic analysis, a deductive approach was used to generate a list of codes from the literature, whereas we used an inductive approach in the content analysis. The inductive approach is typically suited to situations where the researchers have minimal knowledge about the research problem, which was the case with the relationship between open innovation, the defense industry, and the increase in military capabilities. Once the patterns were found in the codes, it was possible to identify the most relevant categories and topics (Tracy, 2013) generating an overview of the data. Overall, the data analysis techniques were helpful to code and analyse a large volume of data (*i.e.*, this study yielded 784 pages). Table 10 presents a summary of what we have been discussing.

**Table 10** – Summary of the methodological approach

Methodological process	Approach used	
Research nature:	Qualitative Research	
Research type:	Multimethod Research	
Research strategy:	Systematic Literature Review	Case Study Research
Sources of data collection:	Scopus database	Semi-structured interviews
		Participant observation
		Official documents
Data analysis techniques:	Thematic analysis	Content analysis
Coding approach:	Deductive	Inductive

Source: Own authorship

Reliability demonstrates that the operations of a study can be repeated with the same results (Yin, 2018). In that regard, we administered the same protocol to all respondents so that the interview process was consistent. The interview transcriptions were also sent to respondents to see if the researchers understood what the interviewee really meant. To ensure validity, this research used triangulation and member checks. That is, we use multiple sources of data collection to confirm the emerging findings and co-authors expertise to verify

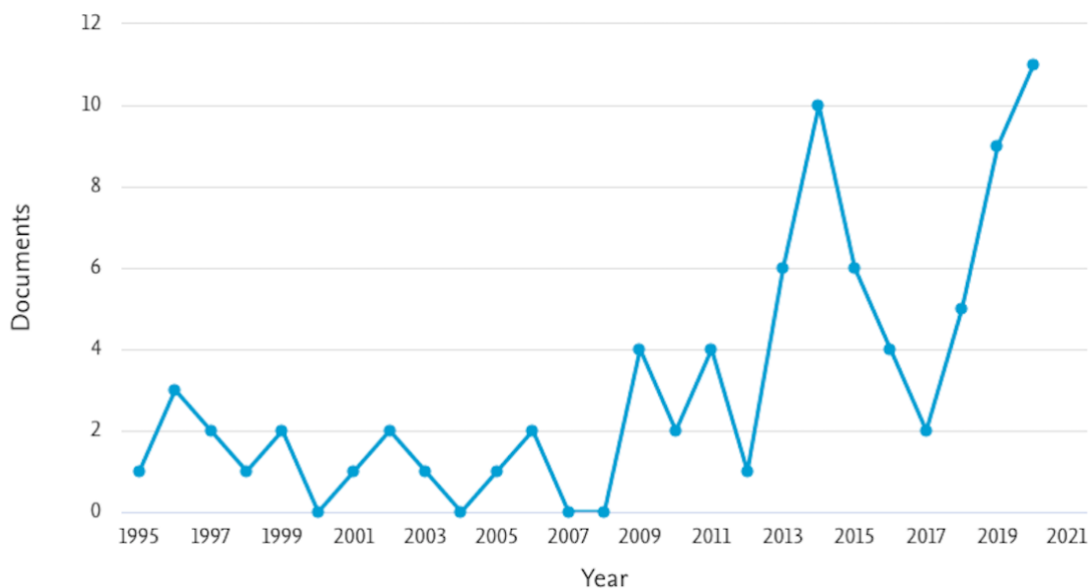


the entire data analysis process for inconsistencies. The connection between reliability and validity rests on the assumption that a study is more valid if repeated observations or replication of the entire study produce the same results (Merriam & Tisdell, 2015). Merriam & Tisdell (2015) also argue that the logic depends on the repetition of events to establish the truth, though several people who experience the same phenomenon do not make the observations more reliable because they can observe it differently.

#### 4.4. Results and Discussion

This section is organised into two sub-sections. First, we describe the state-of-the-art of the defense industry and open innovation, along with the existing conceptual frameworks in the light of the portuguese defense industry. This section also includes the results of the analysis of the case study, showing the contributions of the various sources of data collection to provide a holistic and integrated view of the phenomenon.

Figure 12 – Documents by year



Source: Retrieved from Scopus database

##### 4.4.1. Findings from the SLR

From a timeline perspective, scientific research in defense innovation is far from being straightforward. The most relevant moments are the peak in 2014 and the growing number of scientific research since 2018 (Figure 12). The peak in 2014 may be due to several factors, such as: 1) the liberalisation of defense firms and the erosion of America's defense



innovation; 2) the contribution of defense innovation to the People's Republic of China's (PRC) economic growth; and 3) the environmental footprint reduction of the European Defense sector.

Writing about the US defense innovation, Steinbock (2014) argues that, despite its resilience and superiority, the defense industry shows structural erosion and relative decline. The decline in the US industrial base is related to short-term policies, erosion of domestic defense innovation, and high production costs for limited budgets. In the absence of significant change, the US will tend to lose power to other actors, such as the EU and PRC. On the other hand, Blom *et al.* (2014) suggest that EU defense companies are becoming more efficient and less dependent on public procurement and, therefore, are more likely to share knowledge and collaborate. Thus, it is likely that the dynamics among companies will lead to an increase in the export propensity of the industry and to a less concentrated export market. The argument by Blom *et al.* (2014) is visible in this case study, as it is possible to notice that EDTIB increasingly establishes a dynamic between companies, although with some support from the State. In comparison, the Chinese defense industry is very limited in knowledge production, since the demand for technology comes mainly from civilian areas (Yuan *et al.*, 2016). That is, the defense industry must be integrated into the civilian sector (dual use) to contribute to economic growth more efficiently. In that regard, Reis (2021) also argues that it seems evident that the greater the integration between the defense industry and civil society, the greater the propensity for stability.

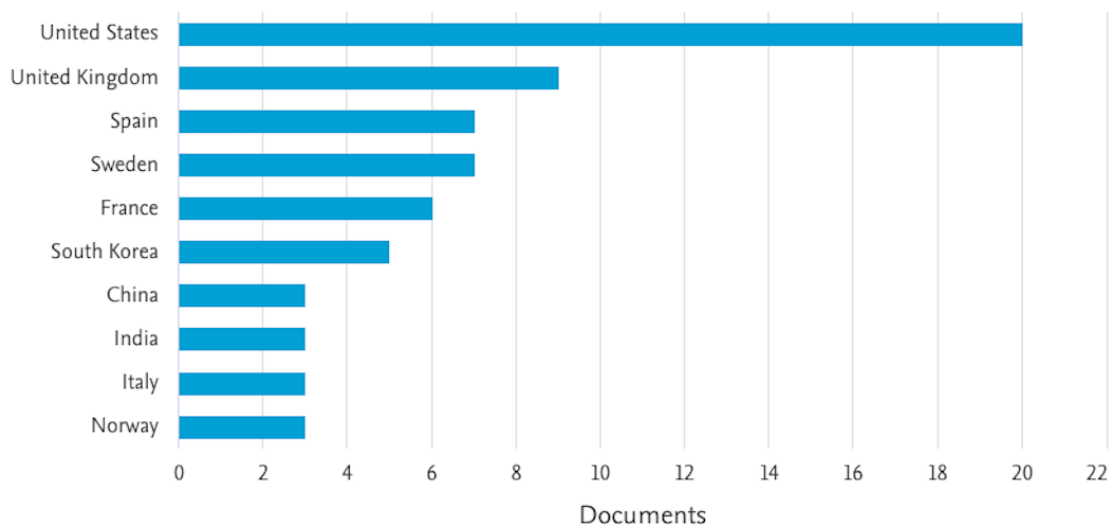
The third most relevant milestone in 2014 is related to the climate and renewable energy objectives of the EU in its efforts for sustainability, environmental protection, and energy efficiency in the various European defense sectors (Fiott, 2014). Fiott (2014) argues that the defense sector is one of the biggest consumers of energy (EDA, 2012), so it is natural that it becomes more environmentally friendly. The reality is that the European defense industry is far from being a "green player," although there is a strong desire to become more environmentally friendly. In this regard, cost-effectiveness and public opinion seem to be the most relevant incentives for military engagement with green practices. Finally, Fiott (2014) also mention that ecological efforts in the European defense sector can be divided by actors: – by the military, such as environmental audits during and after military operations; – by defense companies, in technological innovation to increase military capabilities, as well as in logistics and production processes; – by governments, through European and national regulatory and legislative measures. In this article, we will focus on the second action, that



is, on military innovation, logistics, and increase of military capabilities of ground forces.

The topics responsible for the growing number of publications since 2018 are mainly related to defense innovation and technology transfer of the Spanish defense industry (Briones-Peñalver *et al.*, 2020; Callado-Muñoz *et al.*, 2022; Oliva *et al.*, 2019), the expansion of the Chinese Defense industry (Béraud-Sudreau & Nouwens, 2021; Dominese, 2019), and the Brazilian R&D projects (Bernat & Karabag, 2018; Fernandes *et al.*, 2020; Silva & Olavo-Quandt, 2019). The most notable investment in research refers to the Spanish defense industry, which is also shown in Figure 13 (top 3 countries). The manuscripts from Spain show that strategic alliances favor knowledge and innovation management. In other words, the cooperation agreements favor the process of absorption and diffusion of innovation, facilitating not only learning but also the transmission of knowledge. This analysis aligns with the case study described in the next sub-section, where the strategic alliance between EDTIB companies allowed better dissemination of knowledge and commercialization of innovative military products.

**Figure 13** – Documents by country and territory (up to 15 countries/territories)



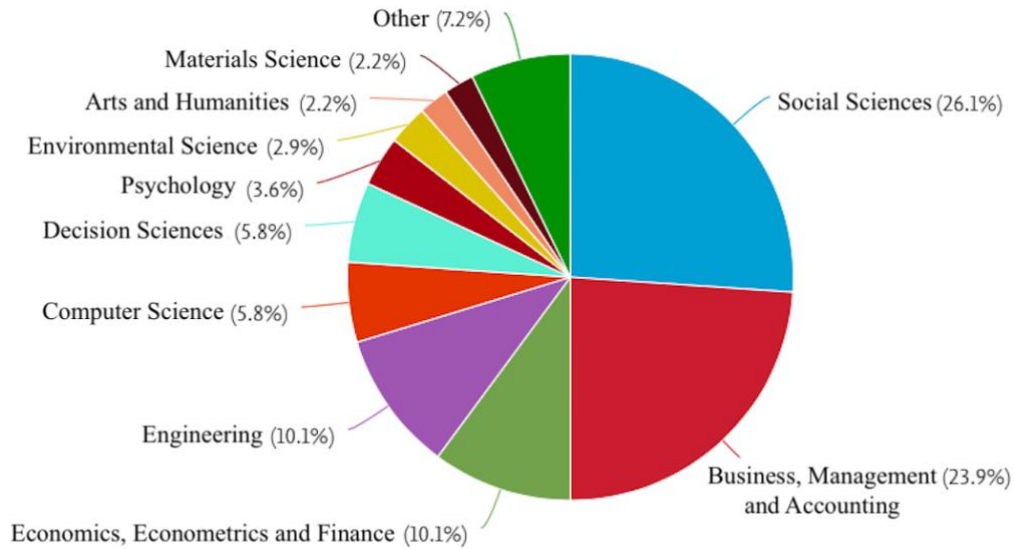
Source: Retrieved from Scopus database

The highest number of articles refer to defense industry innovation in the USA, the United Kingdom (UK), and the EU (Figure 13). Reis (2021) observed that the referred countries have been announcing public measures to support their defense industries. PRC is in 7th place as it still needs to reach a stage of radical or disruptive innovation, for which it still lacks resources and R&D personnel, together with investment in financial resources and willingness to take risks (Béraud-Sudreau & Nouwens, 2021). The previous argument is also justified by Béraud-Sudreau and Nouwens (2021), who stated that although there are



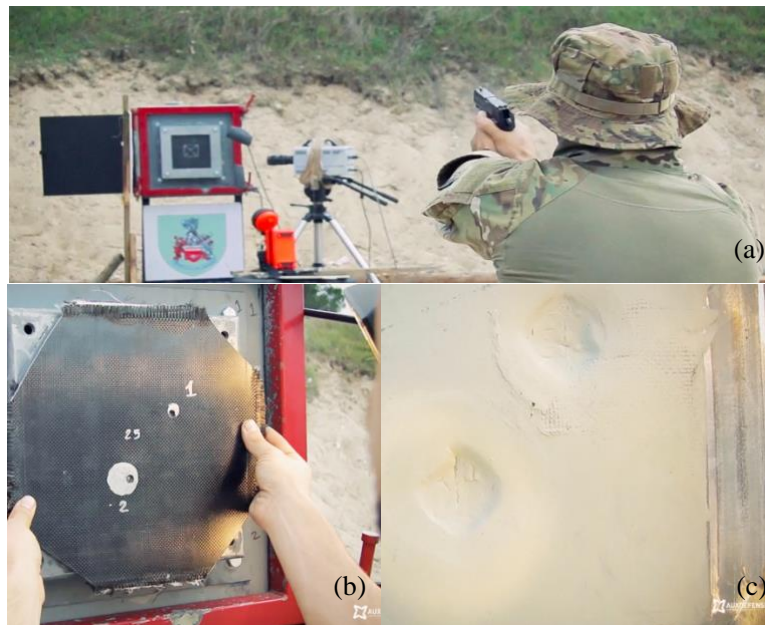
international classifications of Chinese's global defense companies, PRC maintains secrecy of information, resulting in the exclusion of State defense companies from databases.

Figure 14 – Documents by subject area



Source: Retrieved from Scopus database

Regarding the research areas (Figure 14), we were expecting to find the Business, Management, and Accounting, as well as Engineering, as the strongest areas in terms of defense innovation. However, the social sciences is the area that stands out, and there are some explanations for why this happens. If we take a closer look, we realise that social sciences have a relevant role in maximising the social returns of technological and industrial innovation developed by the defense. In that regard, (Yuan *et al.*, 2016) claim that defense innovation has a spill-over effect on the sectors of civil society, and gives some examples of sectors that have benefited from the transfer of defense technological innovation to civil society, as is the case of: 1) the development of the atomic bomb (*i.e.* Manhattan Project) that created the current nuclear industry; 2) the development of computer hardware and software (applications) that was extended to civil society, resulting in a profound social change; or 3) the United States Defense Advanced Research Projects Agency (DARPA), which developed the ARPNET network, the pre-decessor to the Internet. Considering that a large part of the developments comes from the USA, with the end of the cold war, we started to observe a globalised integration of civil-military innovation, which has benefited governments, military institutions, defense companies, and civil society.

**Figure 15** – Pre-test of the bulletproof vest

Source: Adapted from Vilaça (2021): (a) military conducting the pre-test; (b) target impacts; (c) effects on target.

#### 4.4.2. Findings from the Case Research

Open innovation is not simply an outsourcing of research, development, and innovation (R&D&I) activity, but an integration of internal and external competencies (Buganza & Verganti, 2009). While the innovative and high-tech industries demand a high investment in R&D&I, idD soon realized that it could not act in isolation. Therefore, idD sought to work closely with universities and the armed forces. This synergy benefited all stakeholders, particularly the armed forces, which saw their military capabilities increase due to the development of better individual equipment. According to Chesbrough (2003), a firm's relationship with external stakeholders may take place in three different stages: the fuzzy front-end, while accessing new knowledge; the development, buying, or selling solutions; and, commercialization, buying, and selling end products or components. In this case study, this has been achieved through outside-in collaboration with universities and inside-out by collaborative relations with the armed forces, which carried out pre-tests and field tests (Army tested) to improve the defense products (Figure 15).

As presented in Table 9, the Portuguese Defense Industry has a high segmentation, with a total of 380 public and private companies, operating in 20 distinct segments. For that reason, the Portuguese Ministry of National Defense (MND) decided to promote a consortium entitled “Auxdefence.” That partnership brought together the Portuguese Armed



Forces (Army and Air Force), national (University of Minho) and international universities (Hong Kong Polytechnic University and British Plymouth University), and several Portuguese Defense Companies (Latino Group – textile; LMA – textile; Fibrauto – technological materials; IDT Consulting – services; Sciencentris – technological materials). The materials developed resulted from the scientific research and technological development in areas such as, for example, advanced materials, which were designed to build more resistant and lighter equipment, *i.e.*, (a) helmet, (b) bullet-proof vest, (c) knee and elbow pads (Figure 16).

As the Auxdefence project uses knowledge generated by universities, the consortium enabled the development of advanced composite materials, *i.e.*, auxetic textile structures. The auxetic phenomenon is associated with materials with a negative Poisson's ratio that will expand transversally upon the application of tensile forces and vice versa (Lolaki *et al.*, 2022). The auxetic fibrous structures allowed the reinforcement of polymeric matrices and the manufacture of fiber in military equipment garments and components. Despite the abundance of studies on the theory of auxetic materials, few studies have been successful in the transition to practice and production on the desired commercial scale, at least with regard to military equipment (Underhill, 2014). Thus, the ultimate objective of Auxdefence is twofold: to develop innovative defense products and protect ground military forces in the most diverse theatre of operations. In sum, Auxdefence intends to create innovative products to be used by ground military forces, which are based on advanced auxetic structures with high performance in terms of mechanical protection, *i.e.*, technologies capable of absorbing impact and with high capabilities to resist cutting and perforation. Concerning RQ1, open innovation is improving the defense industry to the extent that it has allowed combining the contribution of universities (fuzzy front-end), companies (development and commercialization), and the Armed Forces (Army tested and acquisition). As for the ground forces, they are also primary beneficiaries since their survivable capabilities on the battlefield increase.



Figure 16 – Self-defense equipment for ground combat forces: (a) helmet; (b) bulletproof vest; (c) knee and elbow pads



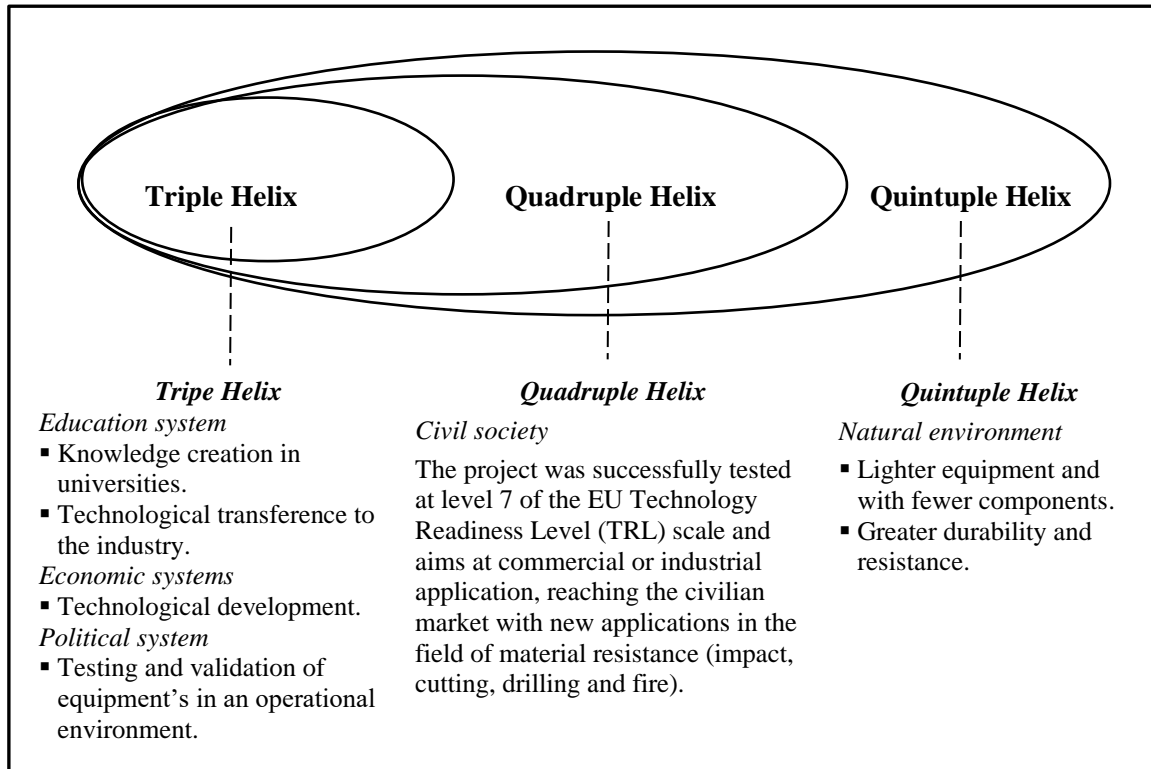
Source: Adapted from Vilaça (2021)

In the context of the quintuple helix, it is foreseen the commercialization of new military products to external military markets. While the project falls under level 7 of the Technology Readiness Level scale, it has in view the eventual industrial and commercial application (Figure 17). It is expected that the transfer of knowledge to companies involved



in the project/consortium allows it to industrialize and guarantee its commercialization in the civilian market. The interest is associated with sectors of activity where the needs for energy absorption, resistance to impact, hardness, and toughness are essential (Evans & Alderson, 2000; Z. Wang & Hu, 2014). For instance, auxetic composite materials present great potential applications where energy absorption is a crucial factor in protection, such as sports activities (Steffens *et al.*, 2021), and aerospace (Wang *et al.*, 2016), among others.

Figure 17 – Self-defense equipment of Portuguese ground combat forces



Source: Own authorship

In addition to cooperation between military entities and the business community, the production of knowledge in universities opens doors to other innovation and technological development (I&DT) projects, scientific production (Fangueiro & Rana, 2020), and the development of patents (Ayerbe *et al.*, 2014). The argument above aligns with Simões *et al.* (2020) article, which analyzed 145 projects of the Portuguese Ministry of Defense and found that academia represented more than 90% of the projects, and 40% of those have a dual-use application. The defense industry also has some specificities when compared to the civil industrial sector, mainly regarding strategic alliances. As argued by Langlois *et al.* (2020), previous research opposed secrecy to open innovation. However, the development of advanced military technologies can likely be carried out based on trust and mutual respect between organizations, as noted in this case. In situations where the bond of trust is broken,



legal mechanisms allow organizations to be excluded from these and future projects.

Regarding the RQ2, the developed products (*i.e.*, helmet, bulletproof vest, knee, and elbow pads) also had an environmental concern (Figure 17); they reduced the use of materials and their weight by about 20% (without losing the expected performance) when compared to the previous equipment in use by the Portuguese armed forces. Using fibrous materials, such as high-performance polyethylene fiber, it was also possible to improve the Portuguese military materials' comfort and ergonomic components. In this regard, anthropometric studies were carried out to adapt the uniform to the soldiers' ergonomics. The reduced weight and better ergonomics of the new uniform allow for increased speed and mobility on the battlefield. For instance, Auxdefence's new developments enabled the modular helmet to resist impacts of 9 mm firearm projectiles, while the ballistic vest can withstand 7.62 mm automatic rifle projectiles. This resistance is partially due to carbon nanotubes, which, in practice, are carbon sheets wrapped in a cylinder that increase the mechanical capabilities of the product when compared to traditional materials (*i.e.*, steel).

The innovative materials were also tested in an operational environment. In that regard, the Portuguese military personnel, deployed in Besmayah – Iraq, whose mission was to train the Federal Police of the Iraqi Security Forces, tested all the developed equipment. We had the opportunity to verify that the military uniforms and tactical equipment were subjected to severe thermal (<45°C) and abrasion conditions. Thus, the integration of textile technologies in the military arena has been instrumental due to its vast, diverse, and complex performance. Some examples aim at: 1) visual protection (camouflage); 2) mechanical protection (ballistic, thermal, etc.); 3) chemical, biological and radiological protection (anti-bacteria, anti-viruses, etc.); and 4) ecological protection, paying due regard to ecosystems and the environment. These are just a few examples that illustrate the relevance of certain military technologies and how they can protect military forces in the light of the quintuple helix innovation model. Although this article presents only one exploratory case, it shows the academic community the relevance of open innovation in building military technologies to protect EU forces in their peace support missions, as well as the need to transfer these technologies to the civilian community.



## **4.5. Conclusions**

The conclusions are divided into four parts. The first and second parts focus on contributions to theory and practice. Then, we present the limitations of both research strategies (*i.e.*, the systematic review and the case study). Finally, we offer some suggestions for future research so that other researchers can follow this study.

### **4.5.1. Contributions to Theory**

This article builds upon the existing theory (Simões *et al.*, 2020), seeking to explore the defense industry in what is known as the quintuple helix innovation model. Thus, this article goes beyond the recent findings of Reis (2021) that suggest the possible existence of a quadruple helix within the scope of the defense industry.

The key arguments that support our results can be summarised in three parts. First, it may be helpful in highly segmented industries to create an entity to manage defense projects (such as Auxdefence). Second, relevant theoretical studies have not been successful in the transition to practice and the desired commercial scale. In that regard, the defense projects have enabled the development of practical applications of academic works, as is the case of polymeric auxetic materials, which are posing new and exciting opportunities in the field of defense applications. Thus, it was possible to give life to new textile products based on advanced technologies for the benefit of the end-user. After being tested and produced on a large scale for the armed forces, the identified self-defense equipment is in condition to be adapted and commercialized to the civilian market (*e.g.*, aerospace, aeronautics, etc.). Finally, it was possible to ascertain that there is a growing concern for the natural environment. Although ecological sustainability was not the primary aim, when combined with military needs and expectations, the project has enabled the development of products with greater durability (*e.g.*, abrasion resistance) and consequently less waste.

### **4.5.2. Managerial Contributions**

Regarding the managerial contributions, it was possible to verify that the triple helix innovation model is not an endpoint, but an intermediate framework that can be extended to the society and the natural environment dimensions. It is recommended that DTIB managers continue their efforts to transition from technological developments in defense to possible commercialization in civil society. Concerns about protecting the natural environment are



increasingly common (Camilleri, 2020; Dzwigol *et al.*, 2020), and the defense industry is not immune to such matters. Therefore, managers working in the defense industry must consider analyzing the natural environment in their proposals, despite the incidence of scientific studies being extremely low compared to other sectors of activity. Finally, there are some relevant opportunities about the R&D&I under PESCO that could be used to develop innovative products for ground military forces. These opportunities can be seized by managers who wish to boost their companies in the military field through EU financial resources.

#### **4.5.3. Research limitations**

This article is not free of limitations. While the systematic review provides a snapshot of a given reality, this research does not cover the entire body of knowledge. However, this limitation is mitigated by the case study, which provides new and complementary outcomes. Moreover, Scopus is constantly being updated with recent and relevant articles, and some of them will likely be left out. Thus, it is necessary to continue investigating the topic to keep the scientific community updated with the most current knowledge. Recognizing the limitations above, we believe that the systematic review still brings added value, as it contributes to a more robust conceptual framework that would not otherwise be possible.

Regarding the case research, one of the limitations stems from the lack of confidence in the credibility of research procedures. This limitation is partly explained by the assumption that quantitative data is more robust when compared to qualitative data since the latter consists of non-numerical information. We believe that the systematic and careful use of the case study can overcome the presented limitation. For instance, to mitigate the limitation above, we used triangulation of several sources of data collection to confirm the findings and interpretations.

Another snag refers to the inability to generalize the results of a case study to a broader level. We will refer to this challenge in future studies, as we do not know whether the quintuple helix innovation model applies to other military contexts and realities.



#### **4.5.4. Recommendations for Future Research**

The Portuguese defense industry is starting to have concerns about the natural environment, as it has developed and produced military equipment with fewer components, lighter and highly durable. However, as Machlis and Hanson (2011) advocated, more research is needed for warfare ecology, notably about the use of ecological models to integrate various impacts of war at the ecosystem level Machlis and Hanson (2011). In other words, there is still a lack of articles published about the quintuple helix innovation model in relation to the defense industry. Future research can also address the issue of generalization by extending this research to countries outside the European context, as they may operate differently from Portugal.





## 5. Chapter V – Quintuple Helix Innovation Model for the European Union Defense Industry: An Empirical Research (ID4)

### Executive Summary<sup>7</sup>

Based on the insights gained from previous articles, traditional innovation models may no longer suffice. Hence, rigorous scientific research was undertaken to ascertain the continued suitability of the Triple Helix (TH) model within one of the world's most influential industries. If the TH model proved inadequate, it became crucial to determine the suitable n-helix variations. To achieve this objective, this article employed an embedded case study research strategy. In pursuit of this strategy, a diverse array of data collection methods was employed, including interviews with military personnel, academics, and professionals from the defense industry and interagencies. Additionally, field notes and official documentation were gathered to bolster and triangulate our findings. The findings revealed a significant trend in the defense industry towards increasing globalization, moving beyond national boundaries, and diluting the role of EU governments as key players. Moreover, we introduced an empirical model to foster innovation within the European defense sector. This research endeavor ended in the creation of a quintuple helix model, with a primary focus on technology and the natural environment. We were able to identify a nexus between technological advancements and environmental considerations in the context of warfare. Although environmental concerns may not traditionally be at the forefront of the Armed Forces' agenda, strides are being taken in this direction. From our perspective, these efforts warrant more practical exploration, much like the in-depth investigation we conducted in our last article. Our findings in that article (ID5) underscore the growing significance of environmental factors in the development and production of military equipment. While some readers may find the results of our analysis somewhat underwhelming, this thesis marks an initial step toward addressing critical environmental issues. Consequently, we aspire to see this subject garner increased attention from both the

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<sup>7</sup> This executive summary serves as an expanded version of the initially published abstract, providing a comprehensive understanding and ensuring alignment among the thesis articles. For citation guidance, please refer to the APA standards. For chapter citation: Reis, J., Rosado, D. P., Ribeiro, D. F., & Melão, N. (2022). Quintuple Helix Innovation Model for the European Union Defense Industry—An Empirical Research. *Sustainability*, 14(24), 16499. <https://doi.org/10.3390/su142416499>. For thesis citation: Reis, J. (2023). Development of an N-Helix Innovation Model for the Portuguese Defense Industry. Military University Institute. Portuguese Ministry of Defense.



academic and industrial communities. In summary, this research concludes that the conventional Triple Helix model may no longer align with the evolving landscape, characterized by the emergence of new supranational actors, such as interagencies. To extend the applicability of the quintuple helix model beyond its current focus on the EU, further scientific inquiry is warranted. Particularly, exploring different national defense policies in Asian and American countries, as we outlined in our initial publication, would be instrumental in this endeavor.

**Keywords:** defense industry; triple helix; N-helix; technology; environment; governments

### 5.1. Introduction

The defense industry is seen as a central instrument of national sovereignty and foreign policy (Sezal & Giumelli, 2022; Simões *et al.*, 2020). The importance is highlighted in the Treaty of Lisbon when European Union (EU) Heads of State and Governments held a debate on common defense (Kollias, 2008). From this debate, they identified a series of cooperation actions within the scope of the Common Security and Defense Policy (CSDP) (Larivé, 2016), stressing the need for an integrated, sustainable, innovative, and competitive EU's Defense Technological and Industrial Base (EDTIB) (Kolin, 2015). Now, with the 2022 Russia-Ukraine war, the European defense industry has gained greater importance.

In this article, we will give particular emphasis to innovation, which is considered a central engine of economic development and growth and competitiveness of companies and nations (Sharma *et al.*, 2022). In that regard, open innovation has become one of the hottest topics in several disciplines (Huizingh, 2011). After Chesbrough (2011) notable publication a decade ago, many companies applied the conceptual guidelines, and many academic and practitioner journals have organized special issues inspired by that book (Chesbrough & Bogers, 2014; Huizingh, 2011; Madanaguli *et al.*, 2022). Therefore, in recent years we have been witnessing a paradigm shift – moving from a “closed innovation” approach, where companies must “generate their own ideas and then develop, build, market, distribute, service, finance and support them on their own” (Chesbrough, 2004, p. 23), to “open innovation”. According to Chesbrough (2011), open innovation requires companies to use external and internal ideas and paths to market as firms seek to advance their technology. The model of open innovations (OI) can be compared with the triple helix (TH), which is composed of three institutional spheres (University-Industry-Government) as the primary



actors (Leydesdorff & Ivanova, 2016; Zhou & Etzkowitz, 2021). The basic view is that the TH model is universal (Etzkowitz, 2019), but almost as soon as it was proposed, observers tried to add additional propellers to address issues beyond innovation (Zhou & Etzkowitz, 2021). Thus, our intention is not to vitiate the original purpose and go beyond the logic of simple additionality. In fact, there are several interpretations of helical models, sometimes deviating from their original intent, which confuses newcomers to the field concerning which helix model to apply in their empirical research (Cai & Lattu, 2022). Thus, our research aims to use the universal TH model within the defense industry.

As we initially did not know how many helices we would find, we defined the following research question (RQ): How does the European Defense Industry operate in the N-Helix model? The RQ allows for filling the GAP in the literature regarding the appropriate innovation model for the defense industry. In the Dutch context, Sezal and Giumelli (2022) found that the triple helix model is suitable for the defense and security industry and that it feeds both the needs of the military defense establishment and the national economy. However, researchers such as Lorenzo *et al.* (2021) and Reis *et al.* (2022a) highlighted that the progress of the defense industry in an unknown n-helix model is a possibility. As far as we know, the literature has evolved from a triple helix to quadruple, quintuple, ..., and an N-Tuple of helices (Leydesdorff, 2012), gravitating around stakeholders, internationalization, specialization, and ecological conservation, which offers various implications and interpretations (Lew & Park, 2021). Due to the numerous interpretations of the set of existing helices, the term N-Helix seemed to be the most appropriate at an early stage of this investigation, avoiding initial bias.

A preliminary presentation of the results suggests a quintuple helix model for the defense industry, focused on technology and the natural environment. In this regard, within the scope of the TH model, the relationship between industry and universities was strengthened, while the relationship with the government weakened due to the entry of international players. Additionally, in the context of the quadruple helix, we show that there has been an increasing use of technologies, highlighting the need to automate the tactical level of warfare. Regarding the quintuple helix, although the results related to the natural environment seem a little disappointing, we identified a growing interest in environmental issues throughout the technological production chain: from development, testing and implementation.

The article is organized according to the following sections: Section 2 will discuss



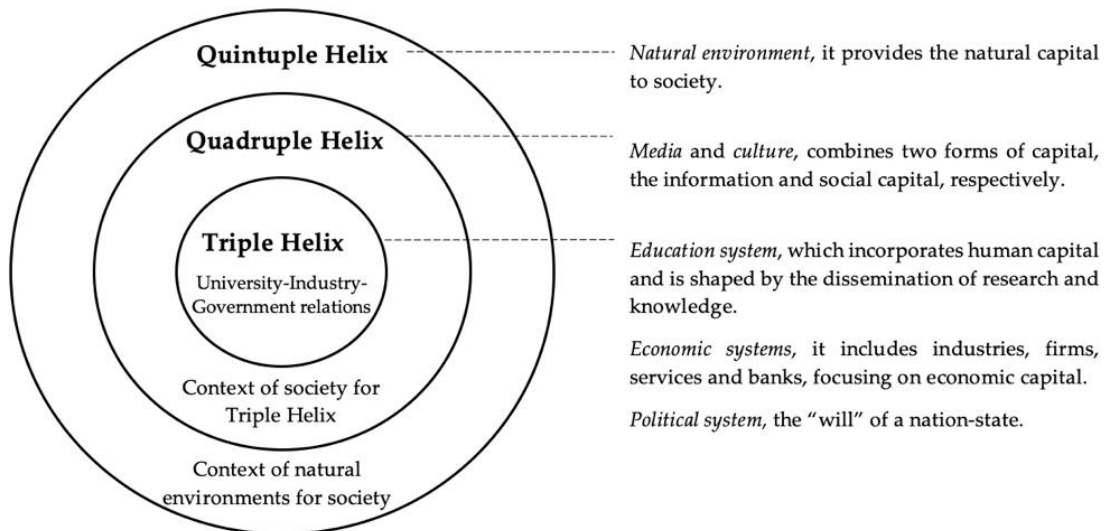
each of the helices providing a holistic perspective; Section 3 will discuss the research design and respective data analysis; Section 4 aims at presenting the empirical model for the defense industry; Section 5 presents the theoretical and managerial contributions, as well as limitations and recommendations for further research.

## **5.2. Conceptual Background**

This section provides the basic concepts for the discussion while describing the N-helix concepts, *i.e.*, the Triple Helix model, devised by Etzkowitz and Leydesdorff (1998, 2000), the Quadruple and Quintuple Helix by Carayannis *et al.* (2012), and the N-Tuple of Helices by Leydesdorff (Leydesdorff, 2012). We end the section with a preliminary discussion of whether the traditional quintuple helix model is suitable for the defense industry.

### **5.2.1. Triple Helix, Quadruple Helix, Quintuple Helix, and N-Tuple of Helices**

The triple helix is widely recognized as a conceptual tool that promotes innovation and entrepreneurship through better understanding, cooperation, and interaction between university, industry and government institutions, and supports economic growth and innovation policy design (Cai & Lattu, 2022; Jovanović *et al.*, 2022). Thus, there is somehow a consensus that TH represents a central model for the production of knowledge and innovation (Carayannis *et al.*, 2022). Meanwhile, the relationship between university-industry-government (UIG) and its indicators has evolved over the last few years, giving rise to new paradigms (Leydesdorff, 2012). Evolution went through the quadruple helix that contextualizes TH by adding “media and cultural audiences” and “civil society” (Carayannis & Campbell, 2009, p. 3). The quintuple helix innovation model is more comprehensive, as it incorporates the “natural environments of society” (Carayannis *et al.*, 2012) (Figure 18).

**Figure 18** – Triple-, quadruple-, and quintuple-helix models

Source: Adapted from Carayannis *et al.* (2022) and Carayannis and Campbell (2012).

Later on, Leydesdorff (2013) also presented his model of the “N-Tuple of Helices”, which can be interpreted in different ways. It can be seen as a meta-reflection and comparison of different approaches to helices to allow for creative designs and re-designs and, at the same time, it also possesses and expresses an “abstract” question (Carayannis *et al.*, 2022). However, while it is not possible to operationalize and show the development in the relatively simple case of three dimensions, Leydesdorff (2013) recommends scholars to be cautious when generalizing beyond the TH model to an N-tuple of helices.

The complexity of the topic is closely related to the issue of a knowledge-based economy, as opposed to a political economy. In other words, the emphasis is on society that is continually disturbed by the transformations that originate from the technosciences (Koshovets *et al.*, 2020). Leydesdorff (2013) refers to the complexity of national innovation systems theory and presents a series of national systems case studies. In that regard, the Netherlands can be considered a national example of innovation. It became a tomato exporting country, although tomatoes do not grow naturally in that country – in a knowledge-based system nothing is taken for granted that cannot be deconstructed and constructed innovatively. This case of a knowledge-based economy made universities more salient in the system, with less need for state action. In Germany, on the other hand, synergies must be made at the level of federal states, and, in the case of Hungary, regional innovation has replaced the national-central system. For example, Budapest remained in a regional-metropolitan and independent system of innovation, while the western part remained in a state-led innovation system, and the western part of the country was integrated into European



innovation systems due to foreign/foreign investments. Leydesdorff (2012, 2013) also mentions that innovation systems can be technology-specific or sector-based. Leydesdorff took the example of Japan, where the UIG relationship has declined despite policies in this direction. This is because academics increasingly co-author with foreign colleagues, favoring internationalization over industrial relevance. Therefore, in Japan internationalization appeared as a fourth dimension in the design, requiring the addition of a fourth propeller to the model. In this regard, Leydesdorff (2012, 2013) imagine a N-tuple or an alphabet of 20+ helices that can be envisioned.

### **5.2.2. Defense Industry – Is the Traditional Quintuple Helix Model Enough?**

An analysis of the literature led us to identify two interesting issues. First, we found that high-tech defense industries are more focused on tactical ground military capabilities (Billing *et al.*, 2021; Kunertova, 2021; Matejka, 2020; Reis *et al.*, 2021a). Therefore, there is a greater focus on technological growth at the tactical level of warfare. Second, it was possible to ascertain a growing concern with ecological sustainability in military operations (Qayyum *et al.*, 2021; Reis *et al.*, 2022a). These two preliminary investigations were red flags for identifying two helices that are expected to be relevant, the technological and the environmental. However, these authors (Reis *et al.*, 2021a; Reis *et al.*, 2022a) present preliminary studies and suggest further research to obtain more solid evidence, which is what we intend to do with this article.

The article by Reis *et al.* (2022a) suggests that industrial activity is operating in a quintuple helix, with the deep involvement of universities and governments in innovation. Additionally, military innovations are being transferred to civil society, with increasing attention to the environment. Several notable authors (Antunes *et al.*, 2022; Figueiro & Rana, 2020) have focused on innovative military materials, which, in some cases, have been tested in operational environments (*i.e.*, Besmayah, Iraq) (Reis *et al.*, 2022a). Such materials included textile technologies that currently equip the Portuguese Army and have been instrumental for military missions abroad. As some of these articles are exploratory (Reis *et al.*, 2022a), our intention is to deepen their results. While we argue that a specific quintuple helix is present for the defense industry based on TH, technology, and environment.



### 5.3. Methodology

This article follows an embedded, qualitative case study research strategy (Yin, 2009). We justify the choice of this research strategy by the need to deepen knowledge about the nexus between technology and the environment in the context of the defense industry. In that regard, the unit of analysis is the Portuguese defense industry (idD Portugal Defense) with embedded case studies (see results section).

Starting by justifying the selection of the subunit of analysis. This article integrates three distinct cases: the first describes the use of TEKEVER's Unmanned Aerial Vehicles (UAVs); the second focuses on focuses on the projects Auxdefence (Advanced Materials for Defense), ACU (Advanced Combat Uniform) and SCS (Soldier's Combat System); the third refers to the warfare ecology managed by idD Portugal. The subunits were selected for convenience sampling, which is a type of non-probabilistic sampling that involves the sample being drawn from a conveniently available group of respondents (Etikan, 2016; Robinson, 2014). In other words, acquiring data in the military context is sometimes a difficult task, given that it is a very closed community and, in certain circumstances, requires some type of security clearance. In this case, the first author was in a privileged position of access to data, both in Portugal and in the theaters of operations, where the materials were tested. Moreover, the idD Portugal Defense was selected for its recent creation (2020) and for having efficiently projected international visibility to the Portuguese Defense Technological and Industrial Base (DTIB) (Reis *et al.*, 2022a). DTIB currently has more than 380 organizations (idD Portugal, 2022). It is a set of public and private institutions, companies, and national scientific and technological centers. idD-Portugal has been representing DTIB in the value chain with some Defense players at a global level (*e.g.*, EU, NATO). We also highlight the mission of idD-Portugal in promoting cooperation between the Armed Forces, companies, universities, and research centers (*i.e.*, TH).

Following recently published articles (Martinho & Reis, 2022), we defined the methodological process in three distinct phases: exploratory, analytical, and conclusive. The exploratory phase began with the search for scientific articles indexed in Scopus on technology and ecology in the defense industry. The preliminary search with the words "defense industry", "technology" and "ecology" in title-abstract-keyword was conducted on January 19<sup>th</sup>, 2022. The search yielded 31 articles that were read in full to obtain a holistic understanding of the existing literature. The exploratory phase also included planning and preparing data collection from various sources, such as semi-structured interviews, direct



observation, and official documentation (Table 11). The preparation included the design of interview protocols (Castillo-Montoya, 2016; Turner, 2014), which were based on information previously collected from existing literature (Cai & Lattu, 2022; Callado-Muñoz *et al.*, 2022; Lawrence *et al.*, 2015), reports and participation in seminars/events organized by idD Portugal.

Planning and preparing data collection included: 1) preliminary contact by a research assistant with respondents (*i.e.*, military personnel, researchers, and experts); 2) the elaboration of research protocols that were based on information previously collected from the literature, reports, and seminars of idD Portugal; and 3) the data collection from the selected sources, which are presented below (Table 11).

We selected highly recognized respondents who could describe the phenomenon from different perspectives. Based on the TH UIG, we selected respondents through convenience (Etikan, 2016; Marshall, 1996) and snowball sampling (Parker *et al.*, 2020) from academic/scientific, industrial, and governmental areas. Specifically, we interviewed: 1) eleven military personnel of different ranks and levels of responsibility who had the opportunity to test military equipment in the Middle East and Central Africa; 2) two academic experts with a strong connection to industry and who developed intellectual property; 3) two managers from NATO Support and Procurement Agency (NSPA), and; 4) three specialists from a private company (part of DTIB) who were responsible for producing military technologies. The interviews lasted between 30-60 minutes, were transcribed in full and sent to the interviewees to avoid misinterpretations. The research was conducted under the Declaration of Helsinki, *i.e.*, respondents gave their permission and signed an informed consent form before participating in the study. In some exceptional cases, we observed that the discussion addressed topics about sensitive military activities, so the interviewees remained anonymous and none of this information was included in the transcripts.

For data corroboration and triangulation, we also carried out participant observation activities, mainly conducted by collecting information through informal conversations and discussions in seminars. In the scope of direct observation, we used a research diary (Mills *et al.*, 2010) to record field notes, such as direct quotes and respondents' behaviors.

Lastly, to obtain greater rigor, we analyzed official documents (*e.g.*, reports) from idD Portugal and military personnel. To avoid presenting an excessive list in Table 11, we have included only a sample of the official documentation.



**Table 11** – Sources of data collection

<b>Military / Rank</b>	<b>Quantity</b>	<b>Position (Place)</b>	<b>Interview date</b>
Lieutenant Colonel (OF-5)	2	NATO HQ Staff (Middle East)	April – May, 2022
Major (OF-4)	3	NATO HQ Staff (Middle East)	March – April, 2022
Lieutenant (OF-2)	2	Command, Training Role (Middle East)	February, 2022
Sergeant First Class (OR-6)	2	Command, Training Role (Middle East)	February, 2022
Sergeant First Class (OR-6)	2	UAV operator (Central Africa)	July, 2022
<b>Experts / Job Title</b>	<b>Quantity</b>	<b>Duty (Place)</b>	<b>Interview date</b>
Academic/Researcher	1	Full Professor (University, Portugal/EU)	March, 2022
Academic/Researcher	1	Assistant Professor (University, Portugal/EU)	March, 2022
Manager/Expert	2	NATO Air Defense Systems Support & Supply (NSPA, Luxemburg/EU)	July, 2022
Director/Expert	1	Executive Director (Private company, Portugal/EU)	March, 2022
Manager/Expert	2	Project Manager (Private company, Portugal/EU)	March–April, 2022
<b>Activity</b>	<b>Quantity</b>	<b>Type (Place)</b>	<b>Direct observation date</b>
Round Table	1	First study on Defense Economy in Portugal (National Defense Institute, Portugal/EU)	December, 2022
Seminar	1	European Defense Fund (Webinar)	February, 2022
Seminar	1	NATO 360°: Business and development opportunities (Webinar)	April, 2022
Seminar	1	European Defense Fund: Challenges and Opportunities (Portuguese Military Academy, Portugal/EU)	April, 2022
<b>Type</b>	<b>Quantity</b>	<b>Title</b>	<b>Official Documents (Publication date)</b>
Report, NATO HQ Staff	3	End of Tour, Mission Reports	2017–2022
Report, idD Portugal	1	Defense Industrial Capabilities in Portugal/EU	July, 2022
Report, idD Portugal	1	Demilitarization & Deactivation of Energy Materials	July, 2022

Source: Own authorship

The analytical phase consisted of processing a significant amount of data (*i.e.*, 6152 pages). To do so, we used content analysis, a widely-known technique from the social sciences ( Scott *et al.*, 2015). We started by reading all the existing content, namely, the interview transcripts, field notes and official documents. We then coded the phrases into categories and subcategories (Wong, 2008). That is, we had to find patterns in the codes, identifying the most relevant ideas (Reis *et al.*, 2022b), allowing us to generate a map that gave us an overview of the data. Moreover, we used a computer-based qualitative data analysis software (QDAS), known as NVIVO 12 (<https://www.qsrinternational.com>, accessed on 27 July 2022). NVIVO 12 allowed to handle a high quantity of qualitative data, reduces the time required for manual handling tasks, increase flexibility and depth in data handling, and provide a more rigorous data analysis (John & Johnson, 2000).



The conclusion phase aimed to interpret, evaluate, describe, and discuss the evidence from the data analysis. In this context, we sought to identify opportunities and contributions related to the nexus between technology and ecology within the defense industry. Finally, we described the research limitations and recommendations to broaden the discussion from a future research perspective.

## **5.4. Results and Discussion**

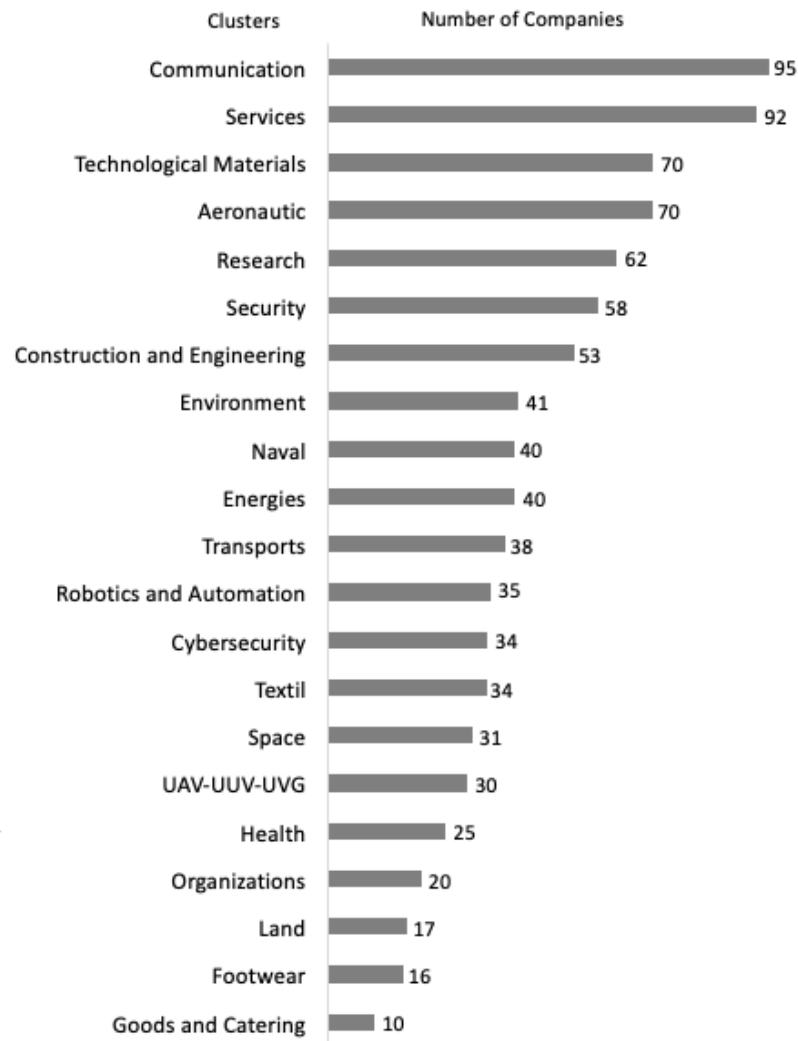
The results showed the Portuguese DTIB was relevant for designing a new empirical model of quintuple helix suitable for the defense industry. The next section presents a description and discussion of the research results.

### **5.4.1. The Portuguese DTIB**

The Portuguese DTIB is currently formed by more than 380 companies, mainly small and medium-sized companies (SME's) with dual use, organized in clusters (idD Portugal, 2022) (Table 12). But, DTIB is more than just private companies, as it includes public institutions, and scientific and technological centers, making a total of 911 organizations (idD Portugal Defense, 2022). These organizations can cooperate with each other and can intervene in one or more phases of the equipment production cycle in defense and other domains, such as Security, Aeronautics, Space and Sea. In other words, cooperation between organizations is usually very close throughout the project for the development of military equipment, resorting to working groups or consortia.



**Table 12** – Portuguese defense technological and industrial base



Source: Adapted from idD Portugal Defense (2022)

The Portuguese DTIB comprises a small number of organizations and, thus, have a flexible structure and are very innovative. The human capital is highly qualified, with knowledge and skills in technological areas and capabilities to develop products and provide services in all military domains. The Portuguese defense industry is also very segmented, being divided into 21 clusters. To promote synergies between companies for the innovation and development of military technologies, a series of consortia have been promoted, as we will see later in this article (see case study 2).

### 5.4.2. Case Study 1 – TEKEVER (Unmanned Aerial Vehicles)

The widespread use of technology in military operations has highlighted several opportunities. This research discloses the contributions of highly technological defense industries, namely the use of mini-UAS (Unmanned Aerial System) and textile technology, designed for military and commercial applications.

The first mini-UAV (Unmanned Aerial Vehicle) used in a real-life situation was the fixed-wing mini-UAV AR4 Light Ray (Figure 19). The manufacturing company, TEKEVER, stresses the equipment is ideal for Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) missions (TEKEVER, 2022, p. 4), although it is not limited to these (*e.g.*, perimeter security, battle damage assessment). TEKEVER is a startup born in the context of a university business incubator (UBI), and it started its activity by developing the first UAV in partnership with the Portuguese army and the University of Aveiro. The company decided to start working within the scope of TH since it could test the materials before entry into operations and testing in real-life situations. The UAV was used in 2014, as part of a Portuguese mission within NATO in Kosovo. AR4 Light Ray was used in Kosovo for reconnaissance and surveillance of large-scale events. In 2022, the Portuguese Army is using UAVs in Central Africa for small tactical military use, *i.e.*, reconnaissance, surveillance, and target acquisition (RSTA).

Figure 19 – TEKEVER AR4



Source: TEKEVER (2022, p. 4)



STA operations are mainly performed by a Mini-UAV system, designed to be operated by two military personnel (*i.e.*, a mission operator and an air vehicle operator) and requires an aircraft (UAV) and a ground control station (GCS) (TEKEVER., 2022, p. 4). The short-range system is launched manually and does not require specific installations, just a vertical adjustment area. The RAVEN is a modern mini-UAV with flight autonomy between 60 to 90 min, covering distances from 48 to 72km at a cruising speed of 26Knots (approx. 48km/h) (RQ-11B Raven., 2022). The RAVEN UAVs were acquired under a contract with the NATO Support and Procurement Agency (NSPA), having been awarded to the US company AeroVironment, to ensure the supply of 12 Raven B Digital Data-Link systems (comprising 3 UAVs each) to the Portuguese Army (Portugal.Gov, 2022).

NSPA, as NATO's main logistics and procurement agency, has been changing the TH paradigm in the EU. Regarding the theory of national innovation systems (NIS). NIS is understood as a “set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts which define new technologies” (Stoneman, 1995). In that regard, the Portuguese DTIB has continued to collaborate with the State and its Armed Forces, because the Armed Forces can test and certify military materials in real-life situations (*e.g.*, Middle East, and Central Africa). After the military prototypes are tested and approved, the natural path for the industry will be to contract military equipment with the State. However, the national defense industry (DTIB), which operates within the scope of TH, may prefer contracts with the local government. In the context of European public procurement, States are committed to contracting at the most competitive market value. In this context, NSPA gains a competitive advantage as it aggregates requests from European states and can negotiate with European defense industries. In this circumstance, smaller EDTIBs find it more difficult to access large European contracts. Therefore, one of the original conclusions of this article highlights that the defense industry is increasingly globalized, leaving the national sphere and weakening the action and participation of EU governments as actors. The EU governments continue to be a player in testing and certification of material in the theater of operations, but not as direct investors. In this context, idD Portugal has provided information on the NSPA to the Portuguese DTIB. The



objective is to increase the turnover of Portuguese defense companies, enhancing their participation in NSPA contracts.

According to the respondents, there are three more issues that deserve due attention. First, UAVs initially designated for military purposes are currently dual use, providing support for forest surveillance and fire detection within the scope of operations to support the special device for fighting rural fires in Portugal. Thus, UAVs are being acquired for civil protection purposes, although the technology developed originates in the DTIB and the military. Second, RAVEN aircrafts operating in Central Africa can allow military units to access hard-to-reach areas, reduce movement and optimize resources in military operations (*e.g.*, energy, fuel), giving strength to the concept of warfare ecology, although this is not the priority of military use. Third, it was possible to ascertain that developing new technologies has given new momentum to the defense industry and military operations regarding tactical operations, where autonomous and/or unmanned systems are being developed. Thus, in this case, it was possible to empirically validate the results previously published in other literature reviews (Billing *et al.*, 2021; Reis *et al.*, 2021a) and provide a better understanding of the phenomenon. That is, in the field of tactical military operations, where decisions are structured (*i.e.*, following orders) and require complex analytical-cognitive tasks (*e.g.*, real-life data acquisition/analysis) (Billing *et al.*, 2021; Reis *et al.*, 2021a), the use of military technologies is confirmed to be rising.

#### **5.4.3. Case Study 2 – Projects Auxdefence (Advanced Materials for Defense), ACU (Advanced Combat Uniform) and SCS (Soldier’s Combat System)**

As mentioned earlier, the DTIB currently has a representation of more than 380 organizations (idD Portugal, 2022) and is highly segmented (+20 distinct segments) (Reis *et al.*, 2022a). To mitigate segmentation and enable better coordination, the Portuguese Ministry of Defense opened a call to promote a consortium that became known as "Auxdefence". According to the respondents, the TH partnerships brought together the Portuguese Armed Forces (Army and Air Force), Portuguese Universities (University of Minho), Technological Platforms (Fibrenamics) and Centers (Technological Center for Textile and Clothing Industries – CITEVE), as well as several private companies (*e.g.*, LMA – textile) (Reis *et al.*, 2022a). The organizations involved in the Auxdefence started working to develop lighter and more resistant military prototypes (*e.g.*, bulletproof vests, helmets,



elbow, and knee pads) based on scientific research. In parallel, the ACU and SCS started working to enable the development of advanced composite materials from auxetic textile structures. These auxetic fibrous structures allow the reinforcement of polymeric matrices and the fabrication of fibers in clothing components and military equipment (Rana & Fanguero, 2016). As Underhill (2014) mentioned, despite the vast literature on auxiliary materials, the transition to industrial production on the desired commercial scale has been difficult. Therefore, Auxdefence/AUC/SCS goal was to develop innovative defense products and put military technologies into drills in different theatres of operations. The technology produced is based on advanced auxetic structures aimed at high performance in terms of mechanical protection, *i.e.*, to develop technologies capable of absorbing impacts and high resistance to cuts. According to the interviews, the battle dress uniform (BDU) and military protection equipment (helmets, bullet-proof vests, knee, and elbow pads) developed with textile technological materials were tested in an operational environment (Figure 20). In other words, Portuguese soldiers deployed on a NATO mission in the Middle East had the opportunity to test the equipment in adverse conditions of heat and abrasion. Like case 1, these materials are just a few examples that illustrate the relevance of certain military technologies and how they can protect military forces considering the TH innovation model.

**Figure 20** – Battle Dress Uniform and Military Protection Equipment



Source: Army Magazine (2022)



According to the experts (Figure 20), there are still three issues that deserve attention. First, the technology developed by Auxdefence/AUC/SCS was to be used essentially at a tactical level for individual protection. In addition to military use, knowledge transfer is expected to enable commercialization in the civilian market. Civil materials are expected to have similar characteristics to military ones, as the interest in civil commercialization is associated with the same needs for energy absorption, impact resistance, hardness, and tenacity. For example, auxetic composite materials have great potential for applications where energy absorption is crucial in protection, such as sports protective gear and equipment, and others (Reis *et al.*, 2022a). Second, the products developed by Auxdefence/AUC/SCS included the environmental issue. In other words, there was a weight reduction of about 20% (without loss of performance), greater resistance, greater comfort/ergonomics, improved temperature regulation (Santos *et al.*, 2019), and durability of the material. Military personnel interviewed who had the opportunity to test the materials in the theatre of operations corroborated the arguments of academic experts and companies. For double validation, the main author of this article tested the auxetic materials firsthand in the Middle East under extreme heat conditions ( $>55^{\circ}\text{C}$ ). Third, there was a consensus among military respondents, academics, researchers, and managers on the need to combine manufacturing with scientific research. For that reason, credit goes to the organizers of the Auxdefence conference series and its publication of scientific knowledge (Fangueiro & Rana, 2020). Moreover, the respondents also stressed the need for greater involvement of military universities and their respective research centers in terms of participation in defense industry projects.

#### **5.4.4. Case Study 3 – Warfare ecology**

We could observe that there is a nexus between technological development and the environment in the realm of warfare. Although the environment is not recognized as a core business of the Armed Forces, some steps are taken in that regard. As far as we know, war has always had the potential to alter the biosphere (Skalny *et al.*, 2021). Note the legitimate concerns about the nuclear issue in the context of Russia's 2022 war with Ukraine. In addition to the destructive effects of nuclear weapons, they have extremely negative effects on the structure and function of ecosystems, drastically altering the habitat and causing losses almost irreversible in the biosphere. Lawrence *et al.* (2015) argues that due to the challenges associated with carrying out research in areas with military activity (*e.g.*,



restricted access), information regarding military impacts on the environment is relatively scarce and is often studied years after the end of military activities. Going back to the situation in Ukraine, after successive attacks on the Zaporijjia nuclear power plant, the International Atomic Energy Agency (IAEA) has still not been able to investigate the site. As mentioned by Lawrence *et al.* (2015), in some specific circumstances, military activity was beneficial when exclusion zones were generated generally resulting in population increase and/or recovery.

One of the most relevant issues identified in the analyzed data was the need for demilitarization, dismantling, and alienation (D3) of military assets. Thus, as a case study, this section focuses on processing end-of-life military systems. Although societies have become increasingly sensitive to environmental issues, the conservation and preservation of natural resources, and energy efficiency, the environmental issue in the military domain continues to be largely neglected. As identified in cases 1 and 2, the environmental question begins to take place in the development and production of military material (albeit limited). However, when it comes to the disposal of military equipment, innovation has fallen far short of expectations.

In Portugal, the D3 is carried out by the idD Portugal. According to official sources, the quality and environment management system is certified according to ISO standards (9001:2015; 14001:2015) and NATO AQAP 2110 certification (idD Portugal D3, 2022). As of 2017, Portugal joined the NSPA D3. From that moment on, it also began to rely on this supranational institution. This put the Portuguese Armed Forces in better conditions to make the most of their end-of-life military equipment. With the adhesion to NSPA D3, the Portuguese government also started arguing that Portuguese private companies linked to the environmental sector would have better access to all tenders of this partnership (National Defense, 2017). As well as the possibility of developing cooperation actions with industries from the current member-states of the program, thus generating new opportunities for Defense Industries.

Traditional government options have been donation, sale, and conversion for training or destruction, but other options exist. In this regard, and according to NSPA respondents, this organization has a clear ambition to introduce green initiatives aimed at reducing energy use and increasing recycling. Yet, more practical dynamics and investment in this regard are needed. While the analysis of this case may seem a little disappointing to the reader, we have identified a clear environmental concern in all data collection sources, from the military on

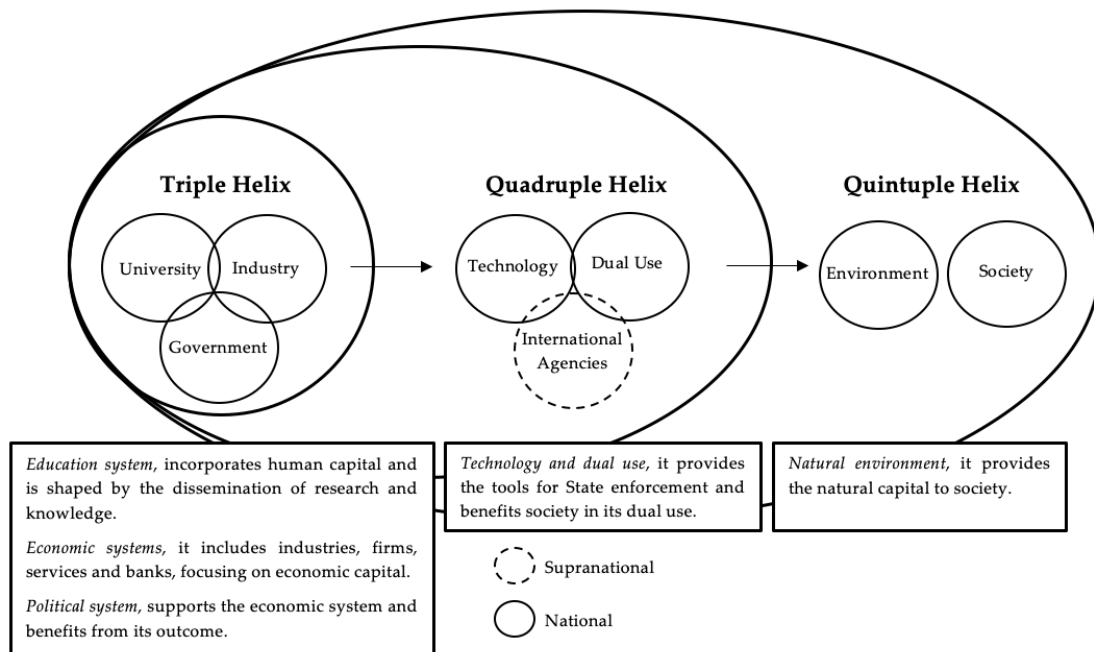


the ground and acting in NATO HQ, to universities, civil companies and NSPA. Clearly, this topic deserves further attention from the academic community; therefore, further research is needed at this point.

### 5.4.5. Empirical Model for the Defense Industry

Due to DTIB's segmentation, the UIG is managed in consortia supported by the government. However, the governments of EU member states are committed to contracting at the most competitive market value. For this reason, supranational agencies, such as the NSPA have gained a competitive advantage (Figure 21). In these circumstances 1) small EU member-state companies (*e.g.*, startups) find it more difficult to access large European contracts; 2) governments are weakened as TH actors, as they are no longer direct investors in DTIB, thus, companies seek to establish new relationships with interagency organizations; 3) DTIB companies maintain a close relationship with universities to seek greater competitive advantage through innovation and knowledge transfer. Briefly, within the scope of the TH, the government will not have the same influence in relation to the traditional TH innovation model.

Figure 21 – Empirical mode for innovation in the European Defense Industry



Source: Own authorship

As far as the research question is concerned, the European Defense Industry operates on the quintuple helix model, although not in terms of the traditional model. Regarding the quadruple helix, the focus is no longer on “media and cultural audiences” and “civil society”,



but on technology and dual use. In this regard, military technology seeks to provide the tools for state enforcement overseas. At the same time, these military innovations are being transferred to civil society, with increasing attention to the environment. Society becomes more relevant downstream, along with the environment, which remains one of the most relevant aspects of the quintuple helix.

## **5.5. Conclusions**

Following recent research (Reis *et al.*, 2022a), we have divided the conclusions into two subsections. The first focuses on contributions to theory and management, and the second on research limitations and suggestions for future research.

### **5.5.1. Theoretical and Managerial Contributions**

The results of this article presented relevant contributions to theory. Firstly, we found that the TH base model is not entirely suitable for the defense industry. If, on the one hand, the industry has sought to obtain greater synergy with universities, in relation to the government, the relationship has weakened. This evidence is because the defense industry is increasingly globalized, leaving the national scope and seeking synergies in the European and international space. Second, we present an empirical innovation model for the European defense industry. The research resulted in proposing a quintuple helix model, mainly focused on technology and the natural environment. Regarding the natural environment, the results can be disappointing, but we have seen a growing concern about incorporating the environmental issue into the entire technological production process: from development, testing, and implementation. Management contributions are related to the empirical validation of results from previously published studies (Christensen & Salmon, 2022; Reis *et al.*, 2021a). In this regard, we have shown by the two presented cases that there has been an increasing use of technologies at the tactical level of war. This result highlights the need to automate the tactical level, and in this regard defense managers should invest their time and resources in research and development. We also recommend greater involvement of universities and military research centers, synergies that are still underexplored by companies.



### **5.5.2. Limitations and Recommendations for Future Research**

This article is limited by its methodological nature. As the research was carried out in a single EU country, it may not present the desired worldwide generalization. As a matter of fact, according to the policy of different regions of the world, there are different approaches to the defense industry (Reis, 2021). For instance, some countries have evidence a integration approach, such as the EU, which has witnessed many acquisitions and mergers within the European defense industry, as well as the coordination of European defense policy and arms procurement through the European Defense Industry (EDA). In other cases, countries present a domination approach, where the defense industry is promoted by the government to become actors on the international arena. The most notable case of domination is the People's Republic of China, which seeks to assume regional dominance through military diplomacy in strengthening military relations with its regional partners to weaken its opponents. Therefore, it is likely that for each approach, different results can be found. However, in our understanding, the results may have some degree generalization at a European level. This argument finds support in the literature with several academic references on technological (Chovančík, 2018; Cowen, 2021) and environmental (Türkalp & Dekkers, 2022) issues for different industries in the EU. Though, we assume that the empirical model may have to be slightly adapted to spatial and temporal circumstances. Further empirical research is needed, especially in Asian and American countries, as they have national defense policies that are significantly different from European ones (Reis, 2021).



## 6. Chapter VI – Green Defense Industries in the European Union: The Case of the Battle Dress Uniform for Circular Economy (ID5)

### Executive Summary<sup>8</sup>

Following the previous article, we made the decision to explore the environmental issues. Firstly, because climate change is at the forefront of the global agenda, and secondly, because the armed forces and other stakeholders in defense must demonstrate their environmental responsibility. For these two reasons, the defense industry should be among the first to devise new strategies and actions aimed at reducing its environmental footprint. Surprisingly, we found no evidence of Circular Economy (CE) practices in the defense industry in the Scopus database. As we will discuss in the conclusions section, we conducted experiments in this regard, yielding zero results by the end of 2022. Despite the absence of prior academic recognition, empirical evidence underpins our assertion of the industry's need for such practices. This is evident from the guidelines issued by the European Commission concerning greener armed forces, as well as the eco-friendly practices adopted in some European Union countries, such as the Netherlands, which we will analyze in this article (ID5). Therefore, this final article of the thesis focuses on the measures being taken by the defense industry and armed forces, and how technology, circular economy (CE), and lean principles can contribute to a more sustainable environment. We employed a qualitative multimethod research approach for this article, encompassing multiple research methods such as systematic literature review and case study research. While the literature suggests that the defense sector in Europe is far from being considered environmentally friendly, a transition towards circular economy practices has been identified. In this regard, the EU's defense sector has played a pivotal role in adopting CE R-strategies, encompassing practices like repurposing, remanufacturing, repairing, reusing, reducing, and rethinking. The integration of new technologies has facilitated improvements in military equipment, enhancing material durability, with EU technological centers playing a key role in the green

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<sup>8</sup> This executive summary serves as an expanded version of the initially published abstract, providing a comprehensive understanding and ensuring alignment among the thesis articles. For citation guidance, please refer to the APA standards. For chapter citation: Reis, J., Rosado, D. P., Cohen, Y., Pousa, C., & Cavalieri, A. (2022). Green Defense Industries in the European Union: The Case of the Battle Dress Uniform for Circular Economy. *Sustainability*, 14(20), 13018. <https://doi.org/10.3390/su142013018>. For thesis citation: Reis, J. (2023). Development of an N-Helix Innovation Model for the Portuguese Defense Industry. Military University Institute. Portuguese Ministry of Defense.



transition. Furthermore, more extensive research is required to enable the generalization of these findings.

**Keywords:** circular economy; climate change; defense industry; environment; lean; R-strategies; technology.

## 6.1. Introduction

With the aim of achieving a climate-neutral European Union (EU) by 2050, the quest for energy efficiency, sustainability and environmental protection has progressively increased. The pursuit of green initiatives is particularly important in the European defense industry, as this sector is one of the biggest consumers of public energy in the EU (EDA, 2022; European Commission, 2022; Fiott, 2014).

After years of containment, the EU left a significant part of its armed forces with equipment below intended capabilities, *i.e.*, in 2021 none of the EU countries were on the top 5 of military expenditure (Silva *et al.*, 2022). In that regard, only eight European NATO member-states have reached the Alliance's target of spending 2% or more of GDP on their armed forces by 2021. With the start of the 2022 Russia-Ukraine war, the European Commission (EC) has decided to increase military spending. Along with that line, Germany has committed to achieving NATO's target of dedicating at least 2% of gross domestic product to defense (1.3% of its GDP in 2021 (Silva *et al.*, 2022)). Though, an increase in military production is likely to make the EU's defense industry one of the less green and sustainable industries, unless key actions are taken.

In mid-2022 the EU announced that it will take steps to invest nearly 1.2 billion euros to support 61 defense industrial cooperation projects (European Commission, 2022c). The European Defense Fund (EDF) is implemented through annual work programs structured in 17 stable thematic and horizontal categories of actions during the period of the Multiannual Financial Framework 2021-2027 (European Commission, 2022b). Unsurprisingly, one of the focuses is: "Boosters and enablers for defense to bring a key technology push to the EDF and which are relevant across capability domains, such as [...] energy resilience & environmental transition [...]" (European Commission, 2022c).

Assessing the green economy and circular economy also requires reliable statistical data, in that regard Stjepanović *et al.* (2017) who saw the need to develop alternative models to Gross Domestic Product (GDP). Such as Green GDP, which provides a clearer perspective



on the consequences of economic progress, offering a new approach to quantifying the cost of ecological and environmental degradation (Stjepanović *et al.*, 2017). Taking a closer look at the Global Green Economy Index (GGEI, 2018) and at the Green Growth Index (GGGI, 2022), it is quite easy to find robust statistics associated with the green economy and in particular our case study. According to the report by Goldschmeding Foundation (Carrone *et al.*, 2022; GGEI, 2018), the citizens of Europe consume an average of 26 Kilos of clothes per year, and in 2019, the estimated turnover of the European textiles and clothing (T&C) value chain amounted to 162 billion euros. This means that the textile industry has grown by around 3% (2.7% in 2019) in the last ten years. Adding to the population growth, the textile industry is an excellent business area to investigate within the scope of the circular economy, which justifies the selection of our case. Although one of the focuses of this research is on the environmental issue, it is necessary to stress that there is a consensus that the dimensions of sustainable development have two more pillars – economic and social. According to Kuhlman and Farrington (2010), the ‘profit’ pillar is seen as the value made by the entire country, expressed as GDP. This then is the economic dimension, and the social dimension (‘people’) concerns human aspirations: equity (translated as income distribution), inclusion (commonly operationalized as employment) and health (expressed by an indicator such as life expectancy or access to medical services). Vallance *et al.* (2011) goes further, defining social sustainability in a triple framework, comprising: (a) basic needs, creation of social capital, justice and so on (known as “development sustainability”); (b) the respect for changes in behavior to achieve biophysical environmental goals (known as “bridge sustainability”); and (c) the preservation of sociocultural characteristics in the face of change, and the ways in which people actively embrace or resist these changes (known as “maintenance sustainability”).

In the academic field, few researchers have addressed the green defense industries. Some relevant examples can be found in the book by Iacovino and Wigell (Iacovino & Wigell, 2022) entitled "Innovative Technologies and Renewed Policies for Achieving a Greener Defense". From this book, we highlight four chapters. First, Wigell and Hakala (Wigell & Hakala, 2022) developed an introduction to greener defense. The authors argued that this issue should have a twofold approach: (1) as climate change advances, defense actors will increasingly need to understand how their strategy and operational conduct may be affected; (2) the defense sector will also need to devise new policies and actions aimed at reducing its environmental footprint. Second, Barberini (Barberini, 2022) stressed that



NATO during its 2021 Brussels summit stated that it intends to become the leading organization in understanding and mitigating the security implications of climate change. Showing the climate issue clearly transcends the borders of the EU. Third, for Nugee (Nugee, 2022), defense needs to understand the implications of climate change, adapting equipment and understanding the need to reduce emissions and become more sustainable. In this regard, defense must adopt a green approach, understand the effects of climate change and the technology that is being developed to adapt and mitigate its effects, becoming more self-sufficient and resilient. Forth, Massa (Massa, 2022) tries to understand how the Defense industry can contribute to the green transition. In this regard, the author identifies five direct means of contribution: (1) develop and implement new sustainable technologies and capabilities, contributing to the green transition; (2) invest in technological innovation to enhance the green transition; (3) reduce the industry's own carbon emissions (First-to-Last-Mile); (4) manage energy consumption and transition to more sustainable energy resources; and (5) the Defense industry should assume the role of enabling the green transition in support of the Armed Forces. From the similar studies presented above, a nexus between the implementation of new technologies and environmental sustainability for a green transition of the defense industry is visible. Thus, this relationship (*i.e.*, technology & environment) will also be one of the focuses of our article, which in line with the existing literature.

Despite the recent and very relevant contributions presented in the literature (Barberini, 2022; Iacovino & Wigell, 2022; Massa, 2022; Nugee, 2022; Wigell & Hakala, 2022), to the best of our knowledge there is still no empirical model for a European Green Defense Industry. To fill this gap in the literature, we present the following research question: How to properly carry out a green transition of the EU defense industry? This research question aims to lay the foundations for how technology and the circular economy have aided the green transition in the European defense industry.

Preliminary results show that the circular economy is of paramount importance within the defense industry, contrasting with the lack of discussion in the literature. We also highlight the relationship between technology and the environment, as the development of technological solutions has enabled leaner strategies with less use of resources and energy.

The next section of this article describes the research methods, highlighting the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) protocol (Moher, 2009; PRISMA-P Group *et al.*, 2015) and the CASP (Critical Appraisal Skills Programme) (<https://casp-uk.net>, accessed on 3 September 2022) (Singh, 2013). Section 3



presents the results of the analysis, including the state of the art, supported by CASP (SM 4) and a synthesis report (Synth Rep) (SM 5). The last section presents the conclusions, synthesizing the theoretical and managerial contributions.

## 6.2. Materials and Methods

This article follows qualitative multimethod research. This option is justified by the need to investigate a contemporary phenomenon within its real-world context (Yin, 2018). This research strategy encompasses the generation of rich knowledge using two or more scientific methods. The methodological choice was drawn upon the existing level of academic agreement that this type of research: 1) is more powerful when compared to single methods (Seawright, 2016); 2) combines unique advantages of corroboration and complementarity, allowing one method to support, improve, and elaborate on the results of the other method (Reis *et al.*, 2019). The selected option deviates from quantitative methods that generally aim to combine or test theories or hypotheses (Brannen, 2017; Morgan, 2015). Building on these arguments, Table 13 provides an overview of the methods used in this research, namely the relationship between methods; furthermore, the design of a conceptual model (SLR) and its empirical validation (case study) also evidence the complementarity between methods.

The first method is a systematic literature review (SLR) that will be supported by the PRISMA protocol, the synthesis report (SR), the CASP programme, and the Scimago Journal Rank (SJR) (<https://www.scimagojr.com>, accessed on 29 August 2022) (Falagas *et al.*, 2008). Data collection was carried out through the the database Elsevier´ Scopus (<https://www.scopus.com>, accessed on 27 August 2022). This method aimed to identify, evaluate, and synthesize the existing literature related to the topic. On the other hand, it also offered the opportunity to find the main theories, concepts, ideas, and debates about the green defense industry.



Table 13 – Multimethod approach design

Method	Sub-method(s)	Source(s) of data collection	Method description	Relationship between methods
Systematic Literature Review (qualitative)	PRISMA Synth Rep CASP & SJR	Elsevier´ Scopus	Identify, evaluate and synthesize the existing literature	Provides the opportunity to learn about the main theories, concepts, ideas, and debates about green defense industries. This method generated theoretical insights for the next phase.
Case study research (qualitative)	Case study research (incl. Protocols)	Interviews, official documents and direct observations	Investigate the phenomenon in its real-world setting with rich contextual data (e.g., interviews) to generate new insights.	This method empirically validates the theoretical insights and build upon these new contributions to theory and practice.

Source: Adapted from Reis *et al.* (2019)

The second method is a case study that allowed to investigate the phenomenon and empirically validate the model. To do so, it was used several sources of data collection, such as semi-structured interviews, official documents and direct observation. The next subsections present the methods used in more detail.

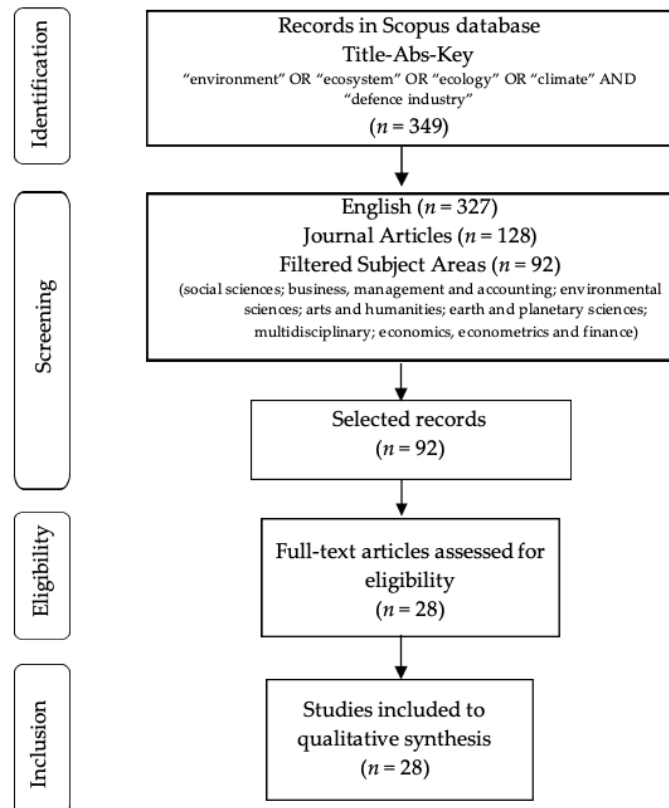
### 6.2.1. Systematic Literature Review

The search was carried out in Elsevier´ Scopus, with article title, abstract and keywords (TITLE-ABS-KEY) to identify peer-reviewed journal articles in English. The search terms were TITLE-ABS-KEY “environment” OR “ecosystem” OR “climate” AND “defense industry”. Usually, SLRs employs more than one database (Reis, 2021). However, we only used a single database since the objective was to achieve more objectively the characteristics of SLRs, which are: transparency, replicability and ease of access (Thomé *et al.*, 2016). Scopus was selected as the largest international and multidisciplinary research database of peer-reviewed manuscripts (Scopus, 2022). An additional argument that justifies the use of Scopus is the coverage of journals in the area of Natural Sciences and Engineering (Mongeon & Paul-Hus, 2016; Reis *et al.*, 2022b), areas typically associated with the defense industry. To refine our research, we used the PRISMA protocol. Thus, in August 2022, Scopus yielded 349 manuscripts (Figure 22). We only included manuscripts in English, for reasons of textual comprehension and interpretation and journal articles for quality reasons (n = 128). Additionally, we only include articles from non-technical areas, namely: social sciences; business, management and accounting; environmental sciences; arts and humanities; earth



and planetary science; multidisciplinary; economics and econometrics and finance. Once the process was concluded, 92 scientific articles were obtained. In the eligibility phase, all article abstracts were read carefully to exclude articles for which we did not have access to the full text ( $n = 8$ ), technical articles ( $n = 7$ ) and articles that had no specific relationship with the topic ( $n = 49$ ). As no article other than the Scopus search was included, we ended up with the approval of 28 articles for review (SM 6).

Figure 22 – PRISMA protocol



Source: Own authorship

The SLR are known to present several limitations: first, SLR are known to present a snapshot of a period of time; therefore, relevant articles that are published hereafter will be naturally left out; second, due to a series of screening filters it is likely that some relevant studies were also not considered for the analysis; third, this research is also limited due to the purely theoretical nature of the results, requiring empirical validation (Reis *et al.*, 2022b).

### 6.2.2. Case Study Research

Since SLR provided theoretical support, enabling a deep and holistic understanding of the phenomenon, the case study consisted of investigating it in its natural environment (Yin, 2018). To this end, we used multiple sources of data collection, including interviews,



document analysis and direct observations. The purpose of using multiple data collection sources is to ensure triangulation and corroboration (Bryman, 2006), not depending exclusively on a single source.

The research focuses on the Battle Dress Uniform (BDU) case and the unit of analysis is the EU armed forces, represented by three subunits. The main subunit is the Portuguese armed forces, supported by the German and Dutch armed forces. The Portuguese armed forces were selected due to convenience sampling, which is a type of non-probability sampling that is characterized by privileged access to respondents (Etikan, 2016); and, the German and Dutch armed forces, to allow European comparison. These latter respondents were chosen by snowball sampling. The snowball technique is one of the most popular sampling method in qualitative research, focusing on the network of contacts and where one respondent suggests another (Berndt, 2020). Although the study included a limited number of respondents (seven Portuguese army officers; five German army officers; four Dutch navy/army officers) we interviewed highly knowledgeable informants, who were able to see the phenomenon from different perspectives. That is, the respondents were chosen according to the different functional areas and different levels of responsibility within the units of analysis. The interviews lasted approximately 45 to 60 minutes and were transcribed verbatim. The research was conducted under the Declaration of Helsinki; thus, all respondents gave their permission and signed an informed consent form before participation in the study. Informal interviews were also carried out, usually collected during field observation. Thus, informal conversations served to clarify data from the interviews. Additionally, a specific protocol was developed, and the data were recorded in a field diary. Organizational documents were collected essentially from open sources (*e.g.*, official website of units of analysis). In the same way as the direct observation, the official documents allowed the triangulation and corroboration of the data obtained in the interviews. Finally, the case studies have limitations that deserve to be mentioned: first, this article does not have the perspective of generalization. That is, the results that concern this case may not apply in another region outside the European context. This limitation can be overcome with more comprehensive quantitative studies; second, case studies are known to be time consuming, so we will continue this research endeavor to deepen some of the knowledge gained in this article.



### 6.2.3. Data Extraction, Synthesis, and Analysis

As mentioned earlier, data were extracted from various collection sources (*e.g.*, Elsevier' Scopus, Interviews). Data were also synthesized, using dedicated reports, programmes and protocols, and analyzed by computer-assisted (or aided) qualitative data analysis software (CAQDAS).

Regarding the synthesis phase, a report was prepared to synthesize the existing knowledge to provide a holistic view of the existing literature. This report included: author(s), year, research question(s), gap(s), method(s), source(s) of data collection data, main finding(s), suggestion(s) for future research (SM 5). Data were then assessed using the CASP, which is a qualitative checklist. The programme is available on the website (<https://casp-uk.net>) and presents all the information necessary to assess the 28 selected articles. In practical terms, CASP examines the selected articles using 10 possible items (SM 4). CASP was a valuable programme to select high-scoring articles and identify the most relevant topics for analysis. The CASP included a secondary layer, by using SJR, which is an internationally recognized platform that identifies the quality standard (quartile) of a journal. Moreover, for the case study, qualitative interview protocols were prepared. The protocols were developed in two formats (*i.e.*, informal conversational and open-ended interviews) in order to obtain dense and rich data (Turner, 2014), allowing the researcher to synthesize and organize the data.

The analytical phase consisted of processing a significant amount of data (*i.e.*, 3246 pages). To do so, we used content analysis, which is a technique widely known in the social sciences (Scott *et al.*, 2015) and which enabled a systematic and objective analysis of the phenomenon (Reis *et al.*, 2020b). The analysis included a CAQDAS (Edlund & McDougall, 2019) using NVIVO12 (<https://www.qsrinternational.com>, accessed on 2 September 2022). This CAQDAS made it possible to integrate, encode and analyze the large volume of data. Once the data was added to the NVIVO 12, the process began with coding the most relevant words and phrases. The coding scheme used the research questions and the SLR as a reference. We then identified the patterns and ideas emerging in the codes, grouping the codes into categories and subcategories. Finally, we looked for patterns by relating codes and categories that were associated to the research question, generating a matrix that provided a more detailed overview of the data.



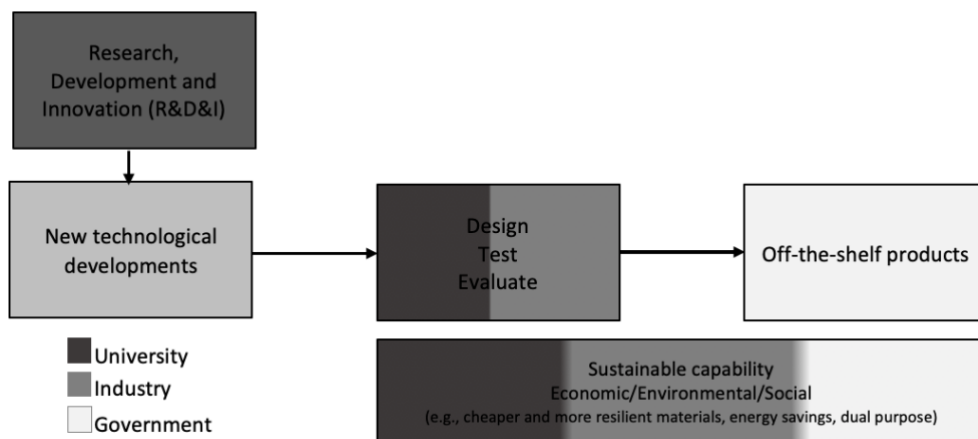
### 6.3. Results and Discussion

The results focus on the theoretical contributions generated by the SRL, and the content analysis assisted in the design of a conceptual framework. The case study empirically validated the theoretical insights, which resulted in a new model that suitable for the defense industry.

#### 6.3.1. Conceptual Framework

From the CASP analysis, 43% of the articles published were Scopus Q1, while the average CASP score is 17 pts (SM 4), which means that the overall quality is good (on a 4-level scale: excellent, good, moderate, and poor). Only 18% of the articles scored excellent (Fiott, 2014; Garfin *et al.*, 2021; Reis *et al.*, 2022b; Sandström, 2004; Saulters, 2007), while 61% good and 21% were of moderate quality. The excellent articles focused mainly on topics such as open innovation (Reis *et al.*, 2022a), adaptation to climate change (Garfin *et al.*, 2021), reducing the environmental footprint (Fiott, 2014), improving technological development in relation to the environment (Saulters, 2007) and transition to green defense (Sandström, 2004). With the lowest score (21%), we found more technical topics related to finance (Sydorov *et al.*, 2020), nanotechnology (Ghorshi Nezhad *et al.*, 2015), and BAE systems (BAE Systems, 2014). This phenomenon is explained by the need for holistic environmental studies that encompass industry, governments, universities, and society. Based on the above information, we present the conceptual framework for the green defense industry. The conceptual framework was developed with information from the articles that achieved the highest score in the CASP.

Figure 23 – Green defense industries: A conceptual framework



Source: Own authorship



The existing literature argues that the defense industry is operating in a triple helix, *i.e.*, universities, governments, and industry (Figure 23) (Fernandes *et al.*, 2020; Jan & Chen, 2005; Silva & Olavo-Quandt, 2019). Thus, society and environment are not found in Figure 2 as is still limited to the triple helix. However, the idea that the defense industry begins to operate in the context of a quintuple helix (civil society and environment) is gaining traction among academics. Justifying the previous argument, Reis *et al.* (2022a) stresses that the defense industry is moving towards a quintuple helix, where military innovations are being transferred to civil society (dual-use) and with increasing attention to the environment. Despite the efforts, the defense sector in Europe is still far from being a holistic green actor (Fiott, 2014). In this regard, Fiott (2014) argues that Europe's armed forces, defense institutions and defense companies exhibit a strong sense of self-interest in greening, embedded in defense market competition and regulation. In addition to the markets and regulations that make the defense industry greener, new technology has been increasingly relevant factors in this transition (Nezhad *et al.*, 2015). Ways of greening the defense sector in Europe could include increasing scientific research and following environmental and circular economy policies, as shown in this article further on. To this end, technology parks, universities and companies in the defense sector can also be very relevant, as they develop the necessary and essential technology for a green transition.

New technologies are not only critical to supporting traditional industrial and military success, but they also play a key role in advancing sustainable development. Saulters *et al.* (2007, p. 281) emphasizes that the “proactive and holistic approach can facilitate efficient research, design, testing, evaluation, and fielding for novel and off-the-shelf products, thereby assisting developers, end users, and other diverse stakeholders in better understanding tradeoffs in the defense industry and beyond”. Some authors go a little further, mentioning that for military organizations the process of organizational greening is a quantum leap, not only technologically, but also mentally (Sandström, 2004).

Although the existing literature is somewhat scattered; in general, from the articles analyzed, we identified specific constructs focused on research, development, and technological innovation (R&D&I). Technologies coming from the triple helix innovation model – where universities, industry, and governments play an active role – are tested and evaluated for use by stakeholders (*e.g.*, armed forces). The attributes and characteristics of off-the-shelf products are expected to be a guarantee of sustainability and transition to a greener industry. The case study presented in the next sections validated the conceptual



model above (Figure 23); however, a new relevant construct was added that has not been previously addressed in the defense industry literature.

### **6.3.2. Circular Economy: Going Back to the Literature**

The initial interviews made us realize that the concept of circular economy (CE) was not referred in the SLR. Interestingly, a quick search on Elsevier' Scopus with the “defense industry” and “circular economy” in tittle-abs-key found no matches. We also learned that in 2016 the European Commission (EC) presented a plan (European Defense Action Plan – EDAP) that incorporates circular economy principles for the defense sector (European Commission, 2022). Due to the empirical centrality of CE and the EC willingness to integrate CE models in the defense sector, we decided to return to the literature to address this need.

CE is seen as “an economic system that replaces the “end-of-life” concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes” (Kirchherr *et al.*, 2017, p. 224). Morsetto (Morsetto, 2020) systematically examined the objectives that make a transition to the CE possible. In this regard, the author presented a framework based on 9 comprehensive and common CE strategies (R-strategies) *i.e.*, recover (R9), recycle (R8), repurpose (R7), remanufacture (R6), refurbish (R5), repair (R4), reuse (R3), reduce (R2), rethink (R1) and refuse (R0) that will be covered in this article. Most of the goals presented in Morsetto' research are related to waste management and resource conservation (R9 & R8). However, these strategies do not necessarily promote a CE by not helping products to remain in the economy. On the other hand, the R7-R0 strategies are the most powerful and for that reason we will focus our attention here. Potting *et al.* (2017) presents three target groups, namely: useful application of materials, extend lifespan of products and their parts, and smarter product use and manufacture. Each of these groups presents a sequence of R-strategies with individual definitions (Table 14).



Table 14 – CE strategies

Target	ID	R-strategy	Definition
Target 3: Smarter product use and manufacture	R0	Refuse	The product abandons its function or offers the same function with a radically different product.
	R1	Rethink	Make the use of the product more intensive. It may involve reworking ideas and concepts, uses and post-uses of a product.
	R2	Reduce	Increase efficiency in manufacturing ( <i>e.g.</i> , energy) or use of products consuming fewer natural resources.
Target 2: Extend lifespan of product and its parts	R3	Reuse	Defined as second use (by another owner) of a product that is still in good condition and can fulfill its original function.
	R4	Repair	Repair and maintenance of a defective or used product so that it can be used with its original function.
	R5	Refurbish	Restore an old product and update it.
	R6	Remanufacture	Use of parts of the discarded product in a new product with the same function.
Target 1: Useful application of materials	R7	Repurpose	Repurpose or decontextualizing is the use of discarded products or their part in a new product with different function.
	R8	Recycle	Extraction of materials from discarded products to obtain the same (high grade) or inferior (low grade) quality.
	R9	Recover	Recovery as material incineration with energy recovery. Refers to waste that is not recycled but is used as an energy source.

Source: Adapted from Potting *et al.* (2017)

The circularity of R-strategies increases proportionately from the incineration of materials with energy recovery to the radical abandonment of redundant products for waste (Lei *et al.*, 2021). The first target includes a set of strategies R9–R8, which refers to solid waste that are destined for landfills or burning for heat recovery. From the processing of these strategies, energy (R9) or materials (R8) are obtained, although the energy conversion efficiency rates are relatively low, and their processing is expensive. However, as argued by Ghisellini *et al.* (Ghisellini *et al.*, 2016) it is in these strategies that most CE policies focus. The second group focuses on R7–R3 strategies with the objective of retaining finished materials and their parts in the economy for a longer period, maintaining or improving their value. For this group to last, it is necessary to have a well-built process, such as reverse logistics and profitable returns for all stakeholders. Note that this process should not prevent progressive innovation and its incorporation or replacement by alternative products or products that have higher standards (*e.g.*, energy efficient, safer, more resilient/resistant). To achieve greater circularity with less consumption of resources, prolonging the useful life of products through reuse, refurbishment and remanufacturing is advantageous as it preserves the usefulness and value of the products (Lei *et al.*, 2021). The use and manufacture of



smarter products (third group) encompasses three R2-R0 strategies, known to be precursory, enabling and transformative (Morseletto, 2020). Within the scope of these strategies, CE occurs even before the start of production (*ex ante*), being closely linked to the manufacturing projects. This is in line with the very definition of CE, which is discussed in the published literature with roots in regenerative design. In that regard, the British Standard Institution (BSI, 2017, p. 10) defines the circular economy as “economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguish between technical and biological cycles” where the restorative/regenerative function of circular economy is pointed out as preventing value loss (Pauliuk, 2018).

### **6.3.3. Green Defense Industry: An Empirical Framework**

Starting with the Portuguese defense industry, idD – Portugal is the entity responsible for implementing a strategy for the national and international promotion of the Portuguese Defense Technological and Industrial Base (DTIB) (National Defense, 2022). Its action focuses on the relationship between the Portuguese Armed Forces, private companies, universities and research centers, and international organizations of which Portugal is a member (idD - Portugal, 2022).

As the Portuguese DTIB is highly segmented (+20 segments) and with a representation of more than 380 organizations, the Portuguese Ministry of Defense decided to create a consortium called "Auxdefence". At the same time, high-level defense projects were developed in parallel, such as the ACU (Advanced Combat Uniform) and SCS (Soldier's Combat System) led by CITEVE (Technological Center for Textile and Clothing Industries).



**Figure 24** – Portuguese Battle Dress Uniform (BDU)<sup>9</sup>



Source: Adapted from the Portuguese Army (2022)

Auxdefence consortium and ACU/SCS projects were operated within the scope of the triple helix, bringing together the Portuguese Armed Forces (Army and Air Force), Universities (*e.g.*, University of Minho), Technological Platforms (*e.g.*, Fibrenamics) and Centers (*e.g.*, CITEVE), as well as several private companies (*e.g.*, LMA – textile). The most relevant projects within the scope of our case study were led by CITEVE. This technological center developed multilayer textiles with innovative auxetic structures, using fibrous materials and advanced structures with high mechanical properties used in the manufacture of clothing components aiming at high performance. The developed BDUs had as main features anti-cut protection, breathability, antimicrobial, and high resistance, being currently used by the Portuguese Armed Forces in national territory and abroad (Figure 24). Before being produced on a large scale for the Portuguese Army, under the qualification system for military systems or equipment, the BDUs received the Army Tested/Combat Proven certificate. Therefore, this evidence is in line with the test and evaluation construct of the conceptual theoretical model (Figure 23).

The above advanced defense materials are giving signs that defense industries are becoming environmentally responsible; becoming relevant actors, as they design R-

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<sup>9</sup> Figure not included in the published version of the article.



strategies and actions aimed at reducing the environmental footprint. Sustainability also incorporates the social and economic dimensions. Starting with the last one, and as we will see further on in this section, the reuse of materials has allowed the Netherlands to make very significant annual savings; in relation to the social issue, the dual use of military materials is fundamental for the scope of innovation and the improvement of citizens' quality of life. According to Portuguese respondents, the BDUs used by the Portuguese armed forces are on the path to a circular defense economy. The argument falls within the scope of the R-strategy for repurposing (R7), remanufacturing (R6), repairing (R4), reusing (R3), reduce (R2), rethink (R1).

At the level of target 1 (Table 14), no case-associated R9–R8 strategies (BDU) were observed. This result is original, as it is on these two strategies that most CE policies focus.

Target 2 involves extending the lifespan of defense products and its parts. In this section, we found three strategies out of five. Within the scope of R7, Portuguese respondents argued about the reuse of camouflage on some occasions. As an example, the interviewees highlight the use of the product with a different function from the original. In other words, Portuguese special operations forces have a tradition of using old BDUs to craft their Ghillie sniper suit. This is an interesting situation that clearly demonstrates that BDUs are reused for training/operational missions. At a time when the demand for sustainability-oriented projects is high, the use of lean philosophies and the simultaneous creation of value has become increasingly important. Within the European Green Agreement (EGA), the Dutch government uses R6 to reuse discarded BDU parts (reducing waste) and incorporate these features into new products with the same function, creating value with fewer resources. Thus, this remarkable example of R6 from the Dutch Ministry of Defense is based on the collection of old uniforms and equipment, being used in the manufacture of new BDUs. This practice has several advantages, as it avoids misuse by third parties (if they are discarded or sold) and avoids incineration, avoiding unnecessary expenses and highly polluting activities. According to the European Defense Agency (EDA), the destruction of materials in the Netherlands cost the Ministry of Defense (MoD) €500 000 a year to destroy materials that still had re-use value (EDA, 2022a). The EDA also mentions that in 2017, the government's central purchasing entity for clothing and personal equipment (KPU) began to apply CE principles. Therefore, KPU managed to extract reusable materials and prolong the useful life of various items, now generating additional annual revenue from €750 000 for the Ministry, while saving 14 500 tones of CO<sub>2</sub> each year. In addition to existing revenues, there are also



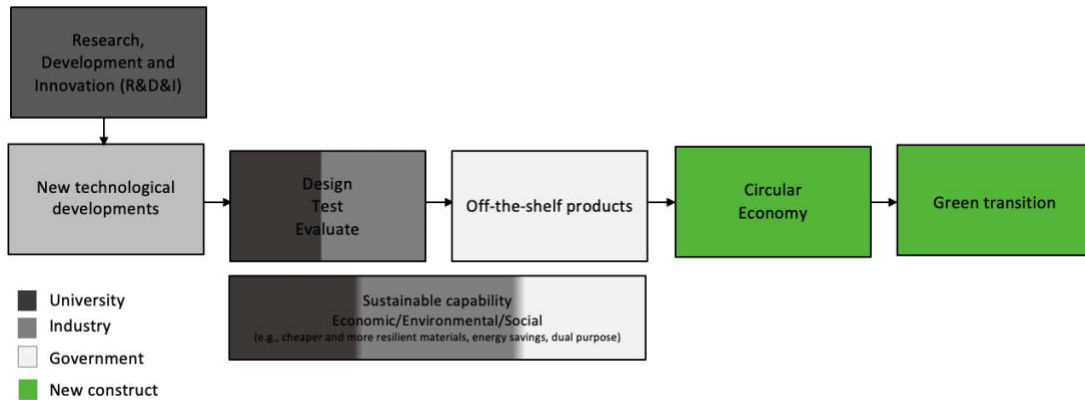
various funding opportunities. For instance, the new Incubation Forum for the Circular Economy in European Defense (IF CEED) generates CE opportunities and policies in the European defense domain through various transnational projects (EDA, 2022b). IF CEED Projects aim to improve the environmental sustainability of the defense sector and contribute to the EU Green Deal. The IF CEED lasts for two years and is managed by the EDA with a financial contribution of €784 000 from the European Commission (LIFE programme) and the Luxembourg Defense Directorate (EDA, 2022b). With regard to R4, when the Portuguese armed forces are assigned to carry out missions abroad, they receive a repair kit, so that they can individually restore the original characteristics of their BDUs. In contrast, German military personnel returning from missions abroad must return their BDUs to be repaired, disinfected, and reused (R3). This situation is not the case for the Portuguese military, who continue to use their own BDUs. In addition, during the interviews we also realized that the donation of defense materials is also a common practice. For instance, the Portuguese BDUs are occasionally donated to the Community of Portuguese Speaking Countries and/or other partner states.

Lastly, target 3 requires making smarter products. In this regard, it identified two of the three possible strategies. As of R2, the use of more resistant and durable BDUs allows to consume of fewer resources, as it is necessary to manufacture fewer textile materials and therefore consume *e.g.*, fewer energy and materials. This is in line with Massa (2022), which stresses the need to manage energy consumption and transition to more sustainable energy resources. R1 followed, in this regard, the defense industry has taken significant steps in Portugal. The interviews, corroborated with official documents (CITEVE, 2022; Vestlife, 2022), showed the occurrence of projects that allow the development of solutions that integrate differentiated materials. For example, the VESTLIFE project aims to develop a new lightweight and modular bulletproof integral solution that incorporates a chemical, biological, radiological, and nuclear (CBRN) detection system (CITEVE, 2022). This protection system will consist of different levels, mainly light and hard armor. The difficulty lies in finding a balanced architecture of materials that allows comfort and protection at the same time. Thus, rethinking is associated with the development of new ideas and concepts that enable the integration of advanced solutions and provide new technological capabilities to BDUs, avoiding the creation of additional equipment. Another example is the STRESSENSE project, which aims to develop sensors/biosensors for the detection and



continuous monitoring of biochemical markers of physical and emotional stress in textiles/clothing.

Figure 25 – Green defense industries in the EU: An empirical framework



Source: Own authorship

Having identified six R-strategies out of nine possible ones, we argue that the defense industry is on track for a successful green transition. What we mean is that there is the possibility of deepening CE activities and analyzing the possibilities of encompassing R5 and R0 strategies in the defense industry. What we mean is that there is the possibility of deepening CE activities and analyzing the possibilities of encompassing R5 and R0 strategies in the defense industry. The empirical framework (Figure 25) supports the idea that the European defense industry is operating on a triple helix. However, the conceptual framework has changed, with the incorporation of the circular economy construct, while the defense industry transitions to the green domain. Which raises the question of whether the defense industry is heading towards a quintuple helix as there is increasing attention to the environment. This argument is also evident in the European Defense Action Plan (EDAP), namely about the need for greater use of energy efficiency measures and renewable energies in the EU armed forces. Therefore, it seems evident that the armed forces, defense institutions, and defense companies in Europe are starting to show an increasingly strong interest in the environmental domain, inserted in the competition and regulation of the defense market, as argued by Fiott (2014).



## 6.4. Conclusions

We draw the conclusions into contributions to theory, that is, what this article adds to the existing literature, and managerial contributions, as we identify the most relevant issues for practitioners working in the defense industry or armed forces. Finally, we propose some brief paths for future research.

### 6.4.1. Theoretical and Managerial Contributions

This article brings new contributions to theory. First, the relevance of CE in the defense industry is evident, in contrast to the lack of theoretical discussion in this regard. In addition, we found several articles discussing the importance of the triple helix (Fernandes *et al.*, 2020; Jan & Chen, 2005; Silva & Olavo-Quandt, 2019), however, this article introduces new evidence that justifies further research to verify whether the EU defense industry operates within the framework of a quintuple helix. Thus, the focus of this article is on the presentation of “technology” and “circular economy” as possible helices. In this regard, we are taking small steps and being very cautious in our arguments, as there is still no clear evidence in the literature that the defense industry operates within a quintuple helix, which is the combination of a triple helix, technology and environment (via circular economy). Second, this article argues that no R9–R8 strategy is associated with the case. According to Ghisellini *et al.* (2016) the R9–R8 strategies that most CE policies focus on, even though the efficiency rates of these strategies are relatively low. This article is original in that it argues that CE policies in the EU defense industry focus on higher targets, which are focused in extending the lifespan of defense products and its parts, as well as to use and manufacture smarter defense products. In this regard, design and re-design replaces the concept of “end of life” with restoration and regeneration, aiming at the elimination of waste through superior design of materials, products, systems and, within that, business models (Kirchherr *et al.*, 2017). Third, this article identifies a number of scientific evidence linking technology and the environment. For example, in target 3 (*i.e.*, smarter product use and manufacture) we highlighted the use of technologies to develop more resistant and durable defense materials, enabling lean strategies with less use of resources and energy. An additional example shows the existence of projects that aim to develop technological solutions that integrate several attributes in a single defense product. These projects therefore allow to reduce the creation of additional equipment, making the defense industry more efficient and affordable. In short, answering the research question, the green transition of the EU defense industry should be



ensured by following the empirical framework and the fulfillment of the identified R-strategies (*i.e.*, currently 6 out of 9 strategies).

We also present three managerial contributions. First, this article suggests increasing discussion among EU member states to fulfill the circular economy targets in the EU armed forces. Thus, it may be important to align strategies and to develop benchmarking activities among EU member states. As an example, we found that German military personnel returning from missions abroad must return their BDUs to be reused (R3), this good practice has not yet been fully adopted by the portuguese military forces. Second, it is necessary to reconcile circular economy and lean principles in the context of the defense industry, in order to create customer-oriented solutions that minimize resource consumption and improve added value for the end user. In other words, the greater the adoption of lean principles in the economy, the greener the EU defense industry will be (Holweg, 2007). Finally, technology centers such as CITEVE have been central to the development of a smart factory vision in the defense industry, developing highly technological apparel models such as the VESTLIFE and STRESSENSE projects. This is in line with Massa (2022) recommendations, where the defense industry and smart factories should assume the role of enabling the green transition in support of the armed forces. Therefore, it is relevant that DTIB managers from the various EU member states understand the importance that smart factories like CITEVE bring to the modernization of the EU defense industry and the military.

#### **6.4.2. Future Research Avenues**

Comprehensive research with multiple cases (*i.e.*, defense materials) and subunits of analysis (EU armed forces) is needed to deepen knowledge and allow generalization. A research of this nature must be developed using EU defense funding and should include a quintuple helix: universities–industry–governments (triple helix), technology (quadruple helix) and environment (quintuple helix). Comprehensive research can also be useful for designing a roadmap for CE in EU defense, as in the notable article by Soufani *et al.* (2018), who focused on the CE roadmap, in this case for the Dutch defense industry. An additional option could be the development of a specific conceptual framework for the CE in the defense industry. The purpose of this research can be twofold: first, to develop CE opportunities to encompass the 9Rs; second, develop more options to reinforce the existing 6Rs.



### **Supplementary Materials**

The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su142013018/s1>, Supplementary Materials: SM 4 – Methodological quality ratings based on CASP (Critical Appraisal Skills Programme); SM 5 – Synthesis report (n = 28); SM 6 – General information of selected articles.





## 7. Conclusion

### 7.1. Relevance of the Outputs and Elements of Innovation

#### 7.1.1. Relevance of the Thesis

To objectively substantiate the significance of our thesis, we searched the Scopus database on September 25th, 2022, utilizing the title-abs-key "defense industry" as our search criteria. Our findings reveal a distinct temporal pattern: a notable growth trajectory spanning from 2015 to 2020, followed by a subsequent decline from 2020 to 2022. This fluctuation can be contextualized by insights from Deloitte (2022), which posits that companies operating within the defense sector experienced a deceleration during the challenging COVID-19 period. However, promisingly, macroeconomic trends strongly suggest a resurgence in the demand for defense equipment, projected to return to pre-COVID-19 levels in 2022.

Moreover, Deloitte's report (2022) underscores the transformative dynamics at play within this sector, with a particular emphasis on the infusion of new technologies, evolving business models, and a heightened propensity for mergers and acquisitions activity. These forces are collectively catalyzing a shift towards digitalization and operational efficiencies. The concept of "smart factories" stands out as a focal point, encompassing several cutting-edge technologies that promise to enhance efficiency and productivity significantly. Consequently, aerospace and defense (A&D) companies that focus on innovation are likely to be better prepared for 2022.

Our exploration of the Scopus database yielded relevant statistics, with 777 documents published in the USA, 385 in the United Kingdom, 240 in China, 192 in Turkey, 149 in India, and 123 in the Russian Federation, establishing the global interest in the defense industry. The European Union's first representative, France, only emerged in 7th place with 95 publications, while Portugal occupies the 30th position with just fourteen documents. This data underscores a conspicuous deficit in scientific publications about the defense industry within the European Union.

Expanding our search parameters by incorporating the term "triple helix" alongside "defense industry" revealed a mere seven documents (Fernandes *et al.*, 2020; Jasi & Bura, 2019; Peeters and Pilon, 2020; Reis *et al.*, 2022a; Silva & Olavo-Quandt, 2019; Simões *et al.*, 2020; Sugiono & Ramadhan, 2018). Further narrowing our focus to the "quintuple helix" yielded a meager two documents (Reis *et al.*, 2022a; Fernandes *et al.*, 2020). This paucity



of scientific peer-reviewed documents concerning the defense industry and its association with triple- and quintuple-helix innovation models underscores the novelty and significance of our contributions to the academic community.

Further emphasizing the pertinence of our thesis, we draw attention to a seminal article authored by Finkbeiner and Van Noorden (2022). In their comprehensive analysis, Finkbeiner and Van Noorden (2022) argue that the Russian invasion of Ukraine served as a catalyst, sparking heightened European interest in augmenting investments in defense research and industry. This geopolitical event catalyzed swift and decisive responses from European nations. Within just three months following the invasion, European countries collectively pledged to augment their defense budgets by a staggering sum, nearing the €200 billion mark. This surge in financial commitments underscores the gravity of the situation and the recognition of the pressing need to fortify defense capabilities across the continent.

While the European Union itself faces certain limitations in terms of substantial budgetary expansions, individual European nations have exhibited a more flexible disposition in swiftly injecting funds into their defense capabilities. One illustration of this commitment is Germany's resolute decision to increase its defense budget by €100 billion, a substantial allocation that will be disbursed over an indefinite timeframe. This resounding financial commitment further underscores the imperative to delve into the defense industry topics—a pursuit that aligns with the core objectives of our research. In essence, the impact of the Ukrainian conflict on European defense investments and the swift and substantial budgetary pledges made by individual nations collectively reaffirm the nature of our investigation into defense industry matters. It is within this dynamic and evolving scenario that our thesis finds its relevance and significance.

### **7.1.2. Originality/Value**

This thesis stands out for its originality on multiple fronts, primarily due to its contribution to the generation of novel insights. First, the innovative core of this thesis focuses on the imperative to enhance the level of intelligent automation within the tactical and operational spheres of warfare (ID2, ID3). This necessity stems from the argument that military personnel engaged in tactical and operational roles typically execute well-defined orders and engage in structured decision-making processes that predominantly involve analytical and cognitive faculties. In such scenarios, the demand for a form of mechanized intelligence becomes evident, warranting the exploration of machine-based alternatives to



human involvement. This, in turn, presents a promising avenue for the defense technology industries to explore and exploit. On the other hand, when it comes to the strategic level of warfare, the use of lethal autonomous weapons systems is subject to more stringent limitations to ensure compliance with ethical, moral, and legal standards established by international bodies such as the United Nations (UN, 2022). To the best of our knowledge, this thesis represents the first instance in which a clear link has been established between military technology, the various levels of warfare, and their implications for industrial production.

Second, our research reveals that the prevailing literature predominantly centers its attention on the triple helix model as applied to the defense industry (Fernandes *et al.*, 2020; Jan & Chen, 2005; Silva & Olavo-Quandt, 2019; Simões *et al.*, 2020). However, the triple helix model alone falls short of addressing the complexities inherent to the defense sector. The innovation models have now transitioned into a quadruple helix paradigm, which not only builds upon the triple helix but also incorporates the essential dimensions of "media and cultural audiences" and "civil society." To further enhance the comprehensiveness of this approach, a quintuple helix model of innovation has emerged, integrating the vital dimension of the "natural environments of society". In our thesis, we explored a comprehensive examination and exploration of the quintuple helix innovation model, which, within the context of the defense industry domain, places particular emphasis on the complexities between technology and the natural environment (ID3, ID4, ID5).

Thirdly, we wish to underscore our contribution to the global academic discourse by disclosing a clear and previously unrecognized connection between the circular economy and the defense industry. Although relevant findings about CE are presented in the ID5 article, it is remarkable that a cursory search using Elsevier's Scopus database, employing the terms "circular economy" and "defense industry" in the title, abstract, and keywords, yielded zero results as of our latest search on September 24th, 2022. This absence of prior academic recognition notwithstanding, empirical evidence substantiates our assertion to the contrary. Our initial evidence emerged from survey respondents and was subsequently validated through official documents, both from the European Union (EU) and the European Commission (EC), along with direct observations made in operational theaters.

This thesis asserts that European Union (EU) defense industry policies are strategically oriented toward achieving ambitious objectives. These objectives primarily revolve around prolonging the operational lifespan of defense products and their constituent parts, while



also promoting smarter use and manufacturing practices within the defense sector. Additionally, this research underscores the substantial scientific evidence that underscores the interconnectedness of technology and environmental concerns. For instance, as highlighted in our discussion in Target 3 (ID5), which centers on the use and production of more intelligent defense products, we underscore the critical role of technology in the development of robust and long-lasting defense materials. This technology-driven approach enables the implementation of lean strategies that significantly reduce the consumption of resources and energy in defense production processes. To ensure the successful transition of the EU defense industry towards environmental sustainability, it is important to adhere to the empirical framework and execute the identified strategies, of which six out of the total nine strategies are currently in progress.

## **7.2. Integrative Perspective, Conclusions, and Future Research**

### **7.2.1. Political and Theoretical Contributions**

To enhance clarity, this section is divided into two distinct parts, encompassing both political and theoretical contributions. In terms of political contributions, this thesis identifies three distinct policy approaches within the defense industry, namely integration, autarky, and domination. This was the first instance where such categorizations have been identified in this manner. Within the context of our thesis, our primary focus is centered on the "integration" approach, primarily as it pertains to the sphere of the European Union. According to the findings from ID1, "integration" entails the process of acquisitions and mergers among various defense industries, all aimed at establishing enduring partnerships that yield specialization and economies of scale.

Autarky and domination represent political approaches that lie outside the scope of our thesis. Autarky involves defense industries striving for independence or self-sufficiency, often relying heavily on state support. In the case of domination, the defense industry is wielded by the state as a political tool to garner power or influence within the international political arena. While ID1 served as a singular study, it provides support to our research. Moreover, the intersection of the defense industry and its relationship with politics has joined increasing scholarly attention, transforming it into an attractive field of research, particularly within the context of crises and armed conflicts, as evidenced in SM1.



Within the area of military operations, ID2 research has unveiled a significant insight into the various levels of warfare, namely the strategic, operational, and tactical levels, each corresponding to distinct Modes. Mode 1, situated at the tactical level, exhibits an inclination towards process automation, where machines are poised to replace human involvement. This indicates a growing trend within the defense industry to integrate disruptive technologies as substitutes for military personnel. Mode 2, operating at the operational level, underscores the importance of human control, signaling a balance between human decision-making and machine assistance. At the strategic level, Mode 3 suggests a different approach – the recommendation here is to infuse certain attributes with human control, even when these functions are currently performed by machines, such as drones. Given the evident shift towards automation in the defense industry, particularly at the tactical level, we have chosen to focus our analysis on military materials employed in this context, such as the battle dress uniform. ID3 builds upon the foundation laid by ID2, aiming to explore the defense industry through the exploration of what is commonly referred to as the quintuple helix innovation model. In doing so, we endeavor to bridge a significant gap in existing literature while aligning with the primary focus of this thesis, which is the development of an N-helix innovation model tailored to the Portuguese defense sector. Through our analysis, it is quite evident that the quintuple helix innovation model (as elucidated by Carayannis & Campbell in 2010) stands as the most suitable framework for the defense industry, albeit requiring certain modifications. In this context, the fourth helix is delineated by the technology dimension, while the fifth helix finds its representation in the concept of the circular economy, symbolizing the commitment to the preservation of the natural environment.

The core arguments supporting the mentioned statements are succinctly outlined in ID3 and ID4. To begin, ID3 underscores the distinctive nature of highly segmented industries, exemplified by the Portuguese Defense-Technology and Industrial Base (DTIB), where collaborative efforts within consortia (*e.g.*, Auxdefence) are leveraged to pioneer disruptive technologies, subsequently transitioning them for use in both military and civilian applications (dual-use). Nevertheless, the introduction of supranational actors may pose a potential challenge, as it has the potential to diminish the sovereignty of EU member states, especially when the DTIB aligns itself with partners who possess the capability to procure its products and equipment. Consequently, it becomes important for EU member states and their Armed Forces, including military research institutions and universities, to cultivate novel strategies and frameworks that enable them to carve a prominent niche within the



scientific and industrial community. This involves the fortification of strategic alliances and the bolstering of the triple helix concept, facilitating a seamless integration of academia, industry, and government to not only preserve their influence but also advance their standing in this rapidly evolving landscape. Secondly, in alignment with the arguments presented in articles ID2, ID3, and ID4 support the idea that the defense industry is progressively becoming more technologically driven. This observation is substantiated by the inclusion of various case studies, such as TEKEVER, Auxdefence/ACU/SCS, and the exploration of warfare ecology. Within this context, a discernible connection between technology and the environment has been identified.

In summary, ID4 introduced an empirical model for the European defense industry, which centered primarily on military defense technologies. However, the findings related to the natural environment left much to be desired, prompting the subsequent publication of ID5. In this latter article, it became apparent that the concept of the circular economy (CE) held significant relevance within the defense industry, despite a noticeable absence of theoretical discourse on the topic. The transition towards a circular economy within the armed forces is particularly significant due to the scarcity of existing literature on this subject. Furthermore, our research served to validate the empirical framework, as we identified six out of nine R-strategies within the case of the BDU.

### **7.2.2. Managerial Contributions**

Regarding managerial contributions, we recommend that DTIB (Defense Technology and Industry Base) managers continue their proactive efforts to bridge the gap between technological advancements in defense and their potential commercialization in civilian sectors. Furthermore, we advocate for a more extensive collaboration between universities, military research centers, and the defense industry, a synergy that remains largely untapped but has the potential to yield significant benefits. Another critical area of concern pertains to environmental protection, an issue that is increasingly prevalent and relevant in today's world, with the defense industry being no exception. In this regard, DTIB managers should seriously consider the integration of circular economy principles into their respective sectors. This entails harmonizing the concepts of circular economy and lean principles within the context of the defense industry to develop customer-centric solutions that simultaneously reduce resource consumption and enhance value for end-users. In essence, the greater the



adoption of lean principles in the economy, the more environmentally sustainable the European defense industry will become.

### 7.2.3. Pulling Together the Contributions

This thesis presents key intersections that facilitate the joining of contributions. One pivotal convergence point in this thesis relates to the methodology employed, where we harnessed certain methods to support others. In essence, this thesis introduces a comprehensive research strategy that empowers the generation of in-depth knowledge through the concurrent application of two or more scientific methods. This approach proves to be significantly more robust than traditional methods, as it capitalizes on the distinct advantages of corroboration and complementarity. In practical terms, our primary approach primarily revolved around systematic literature reviews (SLR) utilizing Elsevier Scopus as the central reference database. The SLR method was instrumental in identifying, assessing, and synthesizing the existing body of literature concerning the defense industry. Moreover, it provided a platform to uncover the prevailing theories, concepts, ideas, and debates about the defense industry. The case studies played a pivotal role in empirically validating the theoretical insights and subsequently building upon them to contribute new perspectives, both theoretically and managerially. From a pragmatic standpoint, while the [ID2](#) article facilitated an exhaustive analysis of the existing literature, offering a comprehensive overview of the defense industry in the context of autonomous systems, articles [ID3](#) and [ID4](#) empirically validated [ID2](#) particularly justifying the increased technological investment at the tactical level of warfare.

An alternative way of pulling together the contributions involves the progressive development of theoretical insights into real-life phenomena, subsequently leading to the formulation of practical solutions. In this vein, our research has revealed instances where defense industry projects have served as fertile ground for translating academic concepts into tangible applications. One compelling illustration of this phenomenon is the case of auxetic polymeric materials, which presented novel and captivating challenges within the realm of defense applications. Our work, as exemplified in [ID3](#), [ID4](#), and [ID5](#) has demonstrated the successful creation of new textile products through the use of advanced technologies, rigorously tested under extreme real-world conditions. While our research may appear, at times, to lean more toward theoretical elucidation, we are actively bridging this gap by pursuing concrete initiatives. To this end, we have initiated a research project in



collaboration with a Portuguese university, aiming to develop software capable of assessing the degree of automation/humanization within a set of autonomous military systems. The initial theoretical groundwork for this project draws from the insights gained in [ID1](#) and [ID2](#). It is worth noting that this project has already received approval and funding, and it is currently in progress. For further details, please refer to Section 1.2.5 on future research avenues.

#### **7.2.4. Research Limitations**

In sum, this thesis bears limitations primarily rooted in its methodological approach to research. Concerning the systematic literature review, it is essential to acknowledge that this thesis offers a snapshot of the current state of knowledge. The dynamic nature of the Scopus database, with continuous updates, raises the possibility that some pertinent research may have been inadvertently omitted from the analysis. Moreover, the application of filters during the review process could potentially result in the exclusion of relevant articles. However, the PRISMA protocol, employed in this study, was designed to enhance the inclusion of pertinent articles, thereby mitigating the effects of potential exclusion. Additionally, we recognize that unlike some original contributions characterized by corroboration and complementarity, not all results in this thesis have undergone empirical testing and validation.

Turning to the case studies, one limitation lies in the perceived lack of confidence in the credibility of research procedures. This reservation partly arises from the belief that quantitative data inherently possess greater robustness when compared to qualitative data, which primarily consists of non-numerical information. Furthermore, there is a challenge related to the generalizability of case study results to broader contexts. To address these limitations, potential alternatives may involve incorporating quantitative methods, which are typically regarded as more robust and conducive to generalizability.

#### **7.2.5. Future research avenues**

Future research in the defense industry should concentrate on the factors that drive European Defense-Technology and Industrial Base (DTIB) entities to pursue synergistic collaborations, considering integration perspectives such as mergers and acquisitions, while others seek state resources (autarky) on the other. This recommendation is rooted in the findings of this thesis, which indicate a diminishing state influence due to the emergence of



supranational actors. Hence, it becomes essential to explore avenues for fostering stronger ties between the defense industry and both national and EU states. To address this challenge, we propose a concept that extends beyond the conventional boundaries of the production industry: the potential use of servitization models. To the best of our knowledge, the adoption of service-oriented business models has the potential to enhance trade relations with states, in contrast to product-centric approaches. While servitization has proven effective in various industrial contexts, its application within the defense industry remains relatively unexplored, necessitating empirical studies to shed light on its viability and benefits.

In [ID4](#), we conducted empirical research within the context of the quintuple helix framework applied to the defense industry. Our work specifically focused on reinforcing the importance of considering technology and the natural environment within this framework. We believe that there is still a notable scarcity of studies addressing this dimension. Consequently, it is not uncommon to come across authors, such as Machlis and Hanson (2011), who emphasize the imperative need for more research in the field of ecological warfare. This entails a deeper exploration of ecological models capable of integrating various ecological impacts of warfare at the ecosystem level. In summary, while our contribution has advanced the understanding of the environmental helix, there remains a significant gap in the literature within the defense industry. [ID5](#), for instance, studied an environmental case (BDU) across three European Union countries, but generalization is needed. Expanding this research to encompass additional European countries and employing various units of analysis presents an avenue for achieving this generalization. Furthermore, we recommend conducting investigations of this nature with the support of EU defense funding, given the substantial scope and scale of the endeavor.

This thesis has also given rise to a project that has undergone submission and approval by the Research Center in Digital Services (CISED) at the Polytechnic Institute of Viseu. This project is centered around the development of intelligent autonomous systems for application in the defense industry. In this context, it is not uncommon for decision-makers to harbor uncertainties regarding which decisions should be delegated to these autonomous systems. The article [ID2](#) has already laid the groundwork by providing theoretical guidelines, advocating for increased automation primarily at the tactical and operational levels of warfare. Simultaneously, it underscores the importance of preserving a higher degree of human involvement at the strategic level. This stance aligns with international laws



and conventions, which assert that the responsibility for the use of weapon systems must remain vested in humans and cannot be delegated to machines. In other words, the relevance of this project is based on its alignment with the directives of the United Nations, particularly those that emphasize the principle of “human responsibility for decisions about the use of weapons systems must be maintained as responsibility cannot be transferred to machines. This must be considered throughout the weapon system lifecycle.” (UN, 2022). In essence, this underscores the critical need for both the Portuguese Armed Forces and the Portuguese Defense Industry (IdD) to establish mechanisms that ensure the humanization of decision-making processes related to lethal actions, firmly avoiding any delegation of these decisions to machines. Thus, an important challenge is to determine the optimal level of human-machine interaction within intelligent autonomous systems. To contribute to the resolution of these complex ethical and operational dilemmas, the project undertaken at CISED aims to identify the key attributes and the precise degree of automation or human involvement within intelligent autonomous systems developed by the military industry in Portugal.

This project represents a significant step towards advancing our understanding of autonomous military systems within the defense industry, with a primary aim of ensuring that the critical decision-making processes about to lethal actions remain under human control. This commitment addresses both legal and ethical concerns surrounding these systems. Concerning its objectives, the project sets forth a comprehensive agenda, centering on the identification of attributes and the assessment of the level of automation and human involvement within autonomous systems developed in Portugal, specifically those operating within Modes 1–3, with a specific emphasis on the strategic level (Mode 3). The anticipated benefits derived from this project encompass the precise determination of the optimal balance between automation and human oversight concerning the attributes of machines and military systems operating across these various Modes. Furthermore, the project promises to contribute valuable scientific insights into autonomous military systems, elevating our collective knowledge in this domain. Ultimately, it aligns with supranational ethical, moral, and legal principles. The culmination of this project will culminate in the development of software capable of quantifying the degree of automation or humanization across a set of attributes within autonomous military systems. Depending on the applicability and broad relevance of the results, the project's final phase may involve the submission of a patent to protect and share these innovative findings with the wider community.



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## Appendix A (with Supplementary Materials – SM)

SM 1 – Prizes/awards of published articles (2021 & 2022 Military Science Research Award & Feature Paper)



Open Access Feature Paper Review

### High-Tech Systems

by João R. and Diana J.

Feature Papers represent the most advanced research with significant potential for high impact in the field. Feature Papers are submitted upon individual invitation or recommendation by the scientific editors and undergo peer review prior to publication.

The Feature Paper can be either an original research article, a substantial novel research study that often involves several techniques or approaches, or a comprehensive review paper with concise and precise updates on the latest progress in the field that systematically reviews the most exciting advances in scientific literature. This type of paper provides an outlook on future directions of research or possible applications.

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**DESPACHO Nº 119/2022**

Assunto: **ATRIBUIÇÃO PRÉMIO «INVESTIGAÇÃO CIENTÍFICA EM CIÊNCIAS MILITARES 2022»**

Nos termos do Despacho 46/2018, de 12 de abril do Comandante do IUM, o qual instituiu o prémio «Investigação Científica em Ciências Militares», do Despacho Nº 55/2021 de 25 de maio, que determina a atual redação do regulamento aplicável, da Ordem de Serviço do IUM 018 de 2022, com a abertura do concurso para o corrente ano, e do Despacho 107/2022 de 1 de setembro, que nomeia o júri, por proposta do júri, que fez a seleção e seriação das candidaturas em reunião que teve lugar no dia 19 de setembro de 2022, determino a atribuição dos Prémio de Investigação em Ciências Militares 2022 aos seguintes artigos:

**1. Área de Estudo das Crises e dos Conflitos Armados**

**"United Nations and the Framework of Disaster Risk Reduction: A Case Study on Adaptation and Sustainable Growth in the Context of Change in the Portuguese Armed Forces"**, Bruno Martinho e João Reis, publicado no *"Journal Sustainability"*, Volume 14, Issue 3, 10.3390/su14031834, 5 de fevereiro 2022 (<https://doi.org/10.3390/su14031834>).

**2. Área de Operações Militares**

**"Defence Industries and Open Innovation: Ways to Increase Military Capabilities of the Portuguese Ground Forces"**, João Reis, Nuno Melão, Joana Costa & Bohuslav Pernica, publicado no *"Journal Defence Studies (Routledge – Taylor & Francis Group)"*, volume 22, issue 3, pages 354-377, 31 de janeiro 2022, (<https://doi.org/10.1080/14702436.2022.2033117>);



## Defense Studies - Decision on Manuscript ID FDEF-2021-0039

Defense Studies <onbehalf@manuscriptcentral.com>

dom 19-09-2021 14:06

### Decision Letter

19-Sep-2021 Dear Dr Reis:

Your manuscript entitled "Defense industries and open innovation: Dynamics to increase military capabilities of the Portuguese ground forces", which you submitted to Defense Studies, has been reviewed. The referee comments are included at the bottom of this letter.

The reviews are in general favourable and suggest that, subject to minor revisions, your paper could be suitable for publication. Please consider these suggestions, and I look forward to receiving your revision.

When you are uploading your revised manuscript, could you please provide: - One version showing the changes you have made to your paper using the track changes mode in MS Word or by using bold or coloured text. You should upload this with the file designation 'File not for review'. - A second 'clean' version without the changes highlighted. This should be uploaded with the file designation 'Main Document - anonymous'.

To submit the revision, log into <https://mc.manuscriptcentral.com/fdef> and enter your Author Centre, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision. Please enter your responses to the comments made by the referee(s) in the space provided. You can use this space to document any changes you made to the original manuscript. Please be as specific as possible in your response to the referee(s).

**IMPORTANT:** Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely publication of manuscripts submitted to Defense Studies, your revised manuscript should be uploaded as soon as possible. If it is not possible for you to submit your revision in a reasonable amount of time, we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to Defense Studies and I look forward to receiving your revision.

Sincerely,

Dr Simon Smith Editor,

Defense Studies

simon.smith@staffs.ac.uk



## **Referee(s)' Comments to Author:**

### **Referee: 1**

Comments to the Author

The paper has quality and relevance in the field of investigation. It is well structured and balanced between the different parts. However, some points should be corrected: the abstract should be more clear as well as the methodology used (referring only to the study case it's not enough information). The Central Question must be there (the main question understudy). At a methodological level, the size of the sample used should be clarified, as well as how it was selected.

### **Referee: 2**

Comments to the Author

The text undertakes important question of expanding scope of non-combat scope of the military activities, leveraging Quintuple Helix innovation model. Similar trend is taking place in business where ESG (Environment, Social and Governance) Indicators are becoming increasingly important for decision-making process, including investment and social perception of a product / brand / company. The composition of the article is correct - it provides clear structure in line with IMRAD approach. The authors found a gap/niche in the research field and attempted (successfully, in my opinion) to address that gap. The use of PRISMA approach is correct, going further, it might make sense to triangulate and check with alternative academic databases (*e.g.*, JSTOR, Springer). However, the results obtained for this research seem robust and exhaustive enough. The analysis and interpretation of the results, including graphic presentation is a value added and strong point of the article.

I would recommend using proof-reading to make the reading more flawless and improve readers' perception of the text. For example, in abstract, the sentence "In addition, military innovations are being transferred to civil society, with deep concerns for the environment" the authors probably should use 'attention' OR 'value attributed' instead of 'concern' (which means: worry). Otherwise, this is a nice contribution to the academic heritage and it would be great to see expanded scope of the article in *e.g.*, edited volume with case studies of other EU/NATO' countries to benchmark and provide best practices for the industry.

## **Cover Letter**

### **Reviewer #1:**

Dear reviewer

Thank you for the opportunity to revise the paper and your recommendations. We re-wrote the article and improved the English. For a better understanding of the new version of the manuscript, we highlighted the text in blue. The text below discusses the detailed comments you have made:

1 – The abstract should be more clear as well as the methodology used (referring only to the study case it's not enough information).

Response: Thank you very much for your contribution. We have revised the abstract accordingly, although the journal's rules restricts this space to a maximum of 200 words.



2 – The central question must be there (the main question understudy). At a methodological level, the size of the sample used should be clarified, as well as how it was selected.

Response: From the two research questions that we had previously presented, we defined a central and a secondary one, taking the opportunity to justify the options. In addition, we have added more details to the methodology section, namely the sample size and how it was selected.

**Reviewer #2:**

Dear reviewer

Thank you for the opportunity to revise the paper and your recommendations. We rewrote the article and improved the English.

For a better understanding of the new version of the manuscript, we highlighted the text in blue. The text below discusses the detailed comments you have made:

1 – I would recommend using proofreading to make it flawless and improve readers' perception of the text.

Response: Thank you for your recommendation. We made a double-check to eliminate typos and grammatical errors. We also asked a colleague from the English department of our university to edit the final version of the manuscript.

2 – It would be great to see the expanded scope of the article *e.g.*, an edited volume with case studies of other EU/NATO countries to benchmark and provide best practices for the industry.

Response: We look forward to following your recommendation, as we have already thought of preparing a call for papers on best practices for the defense industry in the context of EU and NATO' countries. Thank you so much.

September, 2021



SM 3 – Example of the revision process of ID5 – peer-reviewer comments

## Response to the reviewers

### General comments

First, we would like to thank the time you devoted in providing insightful recommendations. We believe that your comments have improved the paper in many ways. We hope you agree that the revised version builds a stronger contribution. For a better understanding of the new version of the manuscript we used Word track changes.

We have taken the revision very seriously. If you feel that the revision has fallen short, we are entirely available to reformulate accordingly. The following paragraphs deal with the detailed comments you raised.

### Reviewer 1

Reviewer point #1: Line 2. Circular Economy. Comment: Please reconcile the triple helix with the CE. The article concluded by suggesting the triple helix + CE = Quintuple helix. Or is it the quadruple helix? Please kindly decide.

Author response #1: The quintuple helix is a combination of triple helix + technology + environment (via the circular economy). The focus of this article is to introduce Technology and Circular Economy as helices. We are taking small steps and being very cautious in our arguments, as there is still no clear evidence in the literature that the defense industry operates within a quintuple helix. Throughout the text we have reinforced this argument to make it clear to readers. Thank you for your comment.

Reviewer point #2: The case study is about BDU which is the Battle Dress Uniform. Why not have it entitled as Green Defense Industries in the European Union: The case of the Battle Dress Uniform for Circular Economy. Your conclusions could dwell on the successful defense industries as they transform to CE. Just a suggestion.

Author response #2: Before submitting the article to the Journal, we contacted the academic editors to analyze the interest the article might generate for the Journal and Special Issue. The response was positive, although a better alignment with the SI was suggested. We will follow and respect the reviewer's recommendation and change the title as recommended.

Reviewer point #3: Line 23 Systematic literature research. Comment: What are the findings in SLR?

Author response #3: We fully agree with your comment. Unfortunately, the abstract can only have 200 words and is therefore very limited. If you wish, we will include the SLR findings, but we will have to remove some of the existing information (*e.g.*, from the case study) to comply with the MDPI rules.

Reviewer point #4: Line 24. A case study research. Comment: What are the findings in the case study? Then reconcile the two findings.

Author response #4: One of the most interesting results is that we found 6 R-strategies out



of 10 in the BDU case (already included in the abstract). There are more interesting results that we would like to include, however we can not go beyond the 200 words.

Reviewer point #5: Line 34. Introduction. Comment: Good Introduction. Very focused on environment. But I suggest the inclusion of the economic and social as well because sustainability normally refers to three dimensions.

Author response #5: We have included your suggestion in the article. Much appreciated.

Reviewer point #6: Lines 72-77. Comments: Will these 5 points be considered writing points in this article. Then draw conclusions could be drawn from these. However, these should be reconciled with the findings in SLR and, case study. Then the ideas in this article are unified. This is just one approach to improve the quality of this article.

Author response #6: This 5-point approach was included in the introduction to demonstrate that similar studies exist. There are points of convergence, although the approach presented is more generic and ours is empirical. We also agree that there is a need for a better alignment between the case and the existing literature. The book chapter that presented the 5-point approach was not part of the SLR results since we only consider Journal articles, however we have made new considerations in this revised version of the article to meet your comments. That is, throughout the text references are made to Massa (2022) that allows to corroborate our results.

Reviewer point #7: Line 105. Collaboration and complementarity. Comments: Yes. Reconcile the SLR and Case study findings.

Author response #7: It is a good observation, thank you. We reinforced this sentence with the argument that Table 1 shows this relationship, but also the design of a conceptual model (SLR) and its empirical validation (Case study) proves that complementarity.

Reviewer point #8: Line 169. Case study research. Comments: Acceptable

Author response #8: Thank you.

Reviewer point #9: Line 241. Industry, governments, universities, and society. Comments: Why is society not found in figure 2?

Author response #9: In the sentence, we argue that there is a need for holistic environmental studies that encompass industry, governments, universities, and society – which is not yet the case. Society is not found in figure 2, as is still limited to the triple helix (TH). This is due the existing literature within the defense industry is still focused on TH. However, the idea that the defense industry begins to operate in the context of a quintuple helix (civil society + environment) is gaining traction among academics. In our opinion, this argument is not yet mature enough, which justify a focus on TH (excluding society and environment from the framework). We clarified this issue in the text.

Reviewer point #10: Line 257: sustainability and sustainable development. Comments: Please define sustainability. Do these refer to economic, environmental and social dimensions?

Author response #10: We have made the sentence clearer and defined the dimensions of



sustainability in the introduction section.

Reviewer point #11: Line 278. Return. Comments: This is necessary. But will this negate the earlier key search words in SLR? If so, how many more articles were related to CE?

Author response #11: Excellent observation. However, one of the results of SLR is the lack of alignment between theory and real life. In fact, we considered that option. But after some discussion we thought it would be useful to inform the academic community about this lack of alignment. Interestingly, if you make a search on Scopus with "defense industry" and "circular economy" (Title-Abs-Key) you will get zero results. Thus, results can be found if you use generic terms, such as "environment". If approved for publication, this article will be the first to use this combination of terms ("defense industry" and "circular economy").

Reviewer point #12: Line 308. Before the start of production. Comments: Please write about design or pre-design. This is important in CE.

Author response #12: We followed your suggestion, thank you.

Reviewer point #13: Line 338. Environmentally friendly. Comments: This is good. Please also address how the BDU could address the economic and social dimensions holistically making up sustainability.

Author response #13: We followed your suggestion, much appreciated.

Reviewer point #14: Line 400. Figure 4. Comments: Please consider capturing economic, environmental, and social in the beginning of the intro instead of limiting to technology and environmental only.

Author response #14: In this case we limited to technology and environment since these are the fourth and fifth helix. However, we added the economic and social issue to bridge the gap with sustainability in the introduction, as previously suggested.

Reviewer point #15: Line 408. Circular economy. Comments: CE = economic, environmental and social. What is the difference between CE and triple helix (institutions)? I suggest you can consider the adoption of CE by the triple helix (the institutions.)

Author response #15: As mentioned earlier, the circular economy was framed within the environmental scope of the quintuple helix. Answering the question, the EC is an helix within the environmental scope. Quintuple helix = triple helix + technology + environment (via the circular economy).

Reviewer point #16: Line 410. Quintuple hélix. Comments: I suggest stick to the CE unless the authors want to reconcile triple helix (institutions) with CE.

Author response #16: We suggest that the defense industry can operate on a quintuple helix. But the field of study needs greater maturity. For this reason we focused our study on Triple Helix + Technology + Environment. In future research recommendations, we argue that more studies are needed to support the quintuple helix theory (with regard to the defense industry). We revised this issue and included additional text in that regard (see 4.1. theoretical and managerial contributions).



Reviewer point #17: Line 432. extending the lifespan of defense products. Comments: This is CE. Please include design or pre-design which is to enable multiple life-cycles. This is one of the definitions in CE literature.

Author response #17: We followed your suggestion, thank you.

Reviewer point #18: Line 444. Targets. Comments: What are the targets of CE? Are they not the three dimensions of economic, environmental and social? Please expand on these.

Author response #18: The targets of CE are mentioned in the Table 2. Target 1: Useful application of materials; Target 2: Extend lifespan of product and its parts; Target 3: Smarter product use and manufacture. We expanded the discussion regarding the targets.

Reviewer point #19: Line 462. universities, industry, governments, societies and environment. Comments: The first three are institutions, the latter 2 are components of CE. But CE should include economic as well. You can rewrite to reflect the three institutions are adopting CE. The case study example is the BDU.

Author response #19: Thank you. This was a mistake, as we referred to: universities, industry, governments (triple helix) + technology + environment = quintuple helix.

Reviewer point #20: Line 468. [www.mdpi.com/xxx/s1](http://www.mdpi.com/xxx/s1). Comments: Not accessible for verification. Please provide access.

Author response #20: We submitted the manuscript and its supplements in a ZIP file. Now we realized that only the manuscript reached the reviewers. We asked the editor to share the supplements with the reviewers. We have also attached the supplement to this review. Thank you for your patience.

## **Reviewer 2**

Reviewer point #1: The article is confusing because the authors talk about Smart Factories in the title and abstract. Still, the full systematic review was conducted looking for elements of circular economy in the EU war industry. What is the concept of Smart Factories, and what is the connection with the Circular Economy? The authors should answer this question by bringing more elements of Smart Factories into the article. If it is not the article's focus, this topic should not appear in the Title, Abstract, and keywords.

Author response #1: Your comment is much appreciated. In fact, it is in line with the reviewer 1. We decided to follow the recommendation of changing the title, abstract and keywords.

Reviewer point #2: The frameworks presented in figure 2 and figure 3 are vague and do not indicate any path to the Circular Economy. The frameworks seem to me much more like a synthesis of what is presented in the analyzed studies and based on the empirical findings of the interviews. But what criteria should the defense industries in the EU follow to implement CE in their processes? What are the criteria or technologies that must be followed or implemented? What starting point should the government have?

Author response #2: With regard to the criteria to be followed by the defense industries in the EU, when implementing CE in their processes, we made a recommendation for future research. Since the BDU case does not have generalization purposes. This option is very



interesting but we need to conduct a broader research with quantitative data. With this article we wanted to present ground-breaking results, since there are no articles linking the EC and the defense industry. In fact, we did this search in Scopus (“defense industry” and “circular economy” in Title-Abs-Key) and we did not get any results. After the publication of this article, we hope to carry out further studies of quantitative nature. Regarding to what criteria or technologies should be followed or implemented, we have tried to expand on this question with results from other similar articles.

Reviewer point #3: A Roadmap could be developed, representing the actors in the supply chain of the defense industries in the EU, indicating which processes each of these actors act, what they provide and how they could contribute to a circular economy.

Author response #3: Your recommendation is very pertinent, however we will need more data. To carry out this research, we went to a theater of military operations, in order to collect data from the German and Dutch armed forces. As we mentioned earlier, we hope to carry out a comprehensive survey with several cases (*i.e.*, defense materials) and in this way start mapping the supply chain. As a reference we cited the article from Soufani *et al.* (2018). A Roadmap to Circular Economy in EU Defense inspired by the case of the Dutch Ministry of Defense.

Reviewer point #4: Finally, improve the quality of figure 1. The article has a lot of potentials, but it needs to be explored a bit more. I wish you a great job.

Author response #4: We have followed your recommendation and improved the quality of all figures. Thank you for all your comments and recommendations.

### **Reviewer 3**

Reviewer point #1: Clarify the main hypothesis of the paper within the abstract as well as within introduction (related to research question).

Author response #1: According to the MDPI the abstract is very limited (up to 200 words), however, following your recommendation we clarified the research question in the introduction section.

Reviewer point #2: Please, eliminate the picture, *i.e.*, figure 3., does not bring relevant point to the discussion.

Author response #2: We followed your recommendation and eliminated the previous figure 3.

Reviewer point #3: Without an adequate measurement framework and robust statistics, evaluation of the green economy as well a circular economy is open to subjective reasoning. The evaluation of ‘green performance’ requires reliable statistical data. Please mention some of the relevant issues, approaches or databases that evaluate the concept on ‘green issues’; especially for the EU area (please mention in introduction or in literature review);

Stjepanović, S., Tomić, D., & Škare, M. (2017). A New Approach to Measuring Green GDP: A Cross-country Analysis. *Entrepreneurship and Sustainability Issues*, 4(4), 574-590.



[http://dx.doi.org/10.9770/jesi.2017.4.4\(13\)](http://dx.doi.org/10.9770/jesi.2017.4.4(13)).

GGEI (2018). 2018 Global Green Economy Index. Green Policy Platform. Retrieved December 9, 2020, from <https://www.greengrowthknowledge.org/research/2018-global-green-economy-index-ggei>.

GGGI (2019). Green Growth Index; Concept, Methods and Applications. GGGI Technical Report No. 5, Global Green Growth Institute.

Author response #3: We have cited and used the information you suggest above.

Reviewer point #4: Could you elaborate more (few sentences) on the (possible) source of funding green defense industries; in general (for the EU) and specific (within your empirical framework in 3.3).

Author response #4: Although the information is very limited for the specific case of BDU, we managed to include some information from the European Defense Agency (EDA).

Reviewer point #5: Page 6, line 251, you mention 'Despite the efforts, the defense sector in Europe is still far from being a holistic green actor'; what should be done in the short run to solve this problem.

Author response #5: Thank you for making us think about this issue. We elaborated further on the question on how to resolve this issue.

Reviewer point #6: Explain the limitations of your research and its reach or conclusions.

Author response #6: We have followed your recommendation. We added that information in the last paragraphs of the sections 2.1. Systematic literature review and 2.2. Case study research.

Reviewer point #7: Conclusion: The paper is written concisely but without firm scientific core (lacks 'strong' analytical approach in respect to multivariate analysis of some kind or even specific econometric methods). The language is appropriate. In general, analysis is correctly carried out and thus contributes to practical judgements. I recommend its publication after minor revisions.

Author response #7: We really appreciated your contribution and motivating words. We hope that expectations regarding our revision do not fall short. Thank you.

The authors,

September 2022



SM 4 – Methodological quality ratings based on CASP (Critical Appraisal Skills Programme)

Study	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Score	Cassification Quality	Scimago
Reis <i>et al.</i> (2022)	Y	C	Y	Y	Y	Y	Y	Y	Y	C	18	Excelente	Q1
Gouvea <i>et al.</i> (2021)	C	C	C	C	C	C	Y	Y	Y	Y	14	Moderate	Q1
Erdağ (2021)	C	Y	C	Y	Y	Y	C	Y	Y	Y	17	Good	Q2
Kordova and Fridkin (2021)	C	Y	Y	Y	Y	C	Y	Y	Y	C	17	Good	Q1
Yeshua-Katz and Efrat-Treister (2021)	Y	Y	Y	Y	Y	C	Y	C	Y	C	17	Good	Q2
Garfin <i>et al.</i> (2021)	C	Y	Y	Y	Y	Y	Y	Y	Y	Y	19	Excelente	Q1
Igić <i>et al.</i> (2021)	Y	C	C	Y	Y	Y	Y	Y	Y	C	17	Good	Q2
Park and Park (2020)	C	C	C	Y	Y	Y	Y	C	Y	C	15	Good	Q1
Sydorov <i>et al.</i> (2020)	Y	C	C	Y	C	C	Y	C	Y	C	14	Moderate	Q2
Fernandes <i>et al.</i> (2020)	C	C	C	Y	C	C	Y	C	Y	C	13	Moderate	Q2
Silva and Quandt (2019)	Y	C	Y	Y	Y	Y	Y	C	Y	C	17	Good	Q3
Coleman (2019)	C	C	N	C	Y	Y	Y	C	C	C	12	Moderate	Q2
Vicente Oliva and Martinez-Sanchez (2018)	Y	C	C	Y	C	Y	Y	Y	Y	C	16	Good	Q2
Bradshaw and Connolly (2016)	Y	C	C	Y	C	Y	Y	C	Y	Y	16	Good	Q2
Hinwood <i>et al.</i> (2015)	Y	Y	C	Y	Y	C	Y	C	Y	Y	17	Good	Q1
Ghorshi Nezhad <i>et al.</i> (2015)	C	C	C	Y	Y	C	Y	C	N	C	12	Moderate	Q3
Fiott (2014)	Y	Y	Y	Y	C	Y	Y	Y	Y	Y	19	Excelente	Q1
[No author name available] (2014)	Y	C	C	C	C	C	Y	C	C	C	12	Moderate	Q4
Emmanuel-Ebikake <i>et al.</i> (2014)	Y	C	Y	Y	Y	Y	Y	C	Y	C	17	Good	Q2
King and Goodman (2011)	Y	C	C	Y	Y	Y	Y	C	Y	Y	17	Good	Q1
Saulters <i>et al.</i> (2010)	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	18	Excelente	Q1
Jan and Chen (2005)	Y	C	C	C	C	C	Y	Y	Y	Y	15	Good	Q3
Barros (2005)	Y	Y	Y	C	C	C	Y	Y	Y	Y	17	Good	Q1
Barros (2004)	Y	Y	Y	C	C	C	Y	Y	Y	Y	17	Good	Q3
Sandström (2004)	Y	C	Y	Y	Y	Y	Y	Y	Y	Y	19	Excelente	Q3
Kapstein (2002)	Y	C	Y	C	C	C	Y	Y	Y	Y	16	Good	Q1
Bates and Kukalis (1998)	Y	C	C	C	C	C	Y	Y	Y	Y	15	Good	Q1
Kapstein (1995)	Y	C	C	C	C	C	Y	Y	Y	C	14	Good	Q3
											Mean	17	

Section A: Are the results valid?

1. Was there a clear statement of the aims of the research?
2. Is the methodology appropriate? Is it worth continuing?
3. Was the research design appropriate to address the aims of the research?
4. Was the recruitment strategy appropriate to the aims of the research?
5. Was the data collected in a way that addressed the research issue?
6. Has the relationship between researcher and participants been adequately considered?

Section B: What are the results?

7. Have ethical issues been taken into consideration?
8. Was the data analysis sufficiently rigorous?
9. Is there a clear statement of findings?

Section C: Will the results help locally?

10. How valuable is the research?



Abbreviations: Y = Yes; C = Can't tell; N = No | Classification: Yes = 2; C = 1 and N = 0 | Overall classification: Excellent = 18/20; Good = 15/17; Moderate 10/14; Poor = >10

SM 5 – Synthesis report (n = 28)

Authors	Research question	GAP	Methods	Sources of data collection	Article main findings (Excerpts taken directly from the articles)	Suggestions for future research
Reis <i>et al.</i> (2022)	RQ1: How is OI improving the defense industry and increasing military capabilities? RQ2: How is the QH innovation model dynamising the military capabilities of ground forces?	If the defense industry and OI allow the establishment of innovative dynamics in the light of the QH	Qualitative multimethod research: Systematic Literature Review & Case Study	Scopus Semi-structured interviews Direct observation Official documents	The results show that, in the light of the quintuple helix innovation model, it was possible to bring applications from theoretical discussion to real life. Moreover, within the scope of the triple helix, it was possible to develop, produce and test military products, allowing to improve the military capacity of ground forces.	In the future, ecological concerns will likely increase, so we suggest a greater focus on this area of research
Gouvea <i>et al.</i> (2021)	Not identified	Not identified	Qualitative research: Comparative study	Not identified	China is increasingly using its trade and investment leverage with both regions to unbalance their defense choices and strategic defense relationships. China's increasing interactions with African and Latin American countries poses a number of geopolitical implications for both the United States and Western European countries.	It is becoming clear that recent developments in China's economy and defense forces are creating a new economic, geopolitical, and defense paradigms around the globe. This new paradigm offers a number of national security challenges and opportunities for the United States and Western European countries in Latin America and in Africa.
Erdağ (2021)	Not identified	To understand the reasons for the military spending of Turkey and analyzes its military spending between 2000 and 2018 when threat perceptions changed significantly.	Quantitative: Expenditure database	This article examines Turkey's military spending between 2000 and 2018 by using Stockholm International Peace Research Institute's (SIPRI) Military Expenditure Database and its effects on bilateral and regional relations.	This article examines Turkey's military spending between 2000 and 2018 by using Stockholm International Peace Research Institute's (SIPRI) Military Expenditure Database and its effects on bilateral and regional relations. It argues that the increase in Turkey's military spending in the 2000s can be explained not only by diversified security threats but also by the quest for autonomy, the desire to be a regional actor, economic capacity increase, efforts to nationalize the defense industry, and the North Atlantic Treaty Organization (NATO) alliance's inability to form a sufficient umbrella time in the face of security threats, notably in the face of missile threats. The results show that the traditional alliances and strategic cooperation do not guarantee Turkey's military demands, and its military spending increases, while the proportion of military spending in GDP falls, due to economic growth.	Not identified
Kordova and Fridkin (2021)	Not identified	The need for an effective, efficient approach to risk management is considerably more important for defense industries, because	The research paradigm combined analytical, quantitative, and qualitative methods.	This paper uses heterogeneity and homogeneity analysis between risk factors with Cochran's Q test and multidimensional scaling in order to present the complexity of the risk factors relevant to defense systems of systems	Findings from an in-depth analysis of 46 classified defense SoSs shows a need to focus on three main risks faced by defense projects: insufficient human resources, changes in the original specifications, and lack of other (nonhuman) resources.	This paper presented results of a data science analysis of 46 classified defense SoSs. The authors recommend that future research expand the study to other defense industries in additional countries, with different clients and suppliers.



<p>Yeshua-Katz and Efrat-Treister (2021)</p>	<p>What are the perceived cultural and social factors that contribute to the innovation culture in Israel?</p>	<p>they are exposed to risk in the early stages of development.</p> <p>The Israelidefense industry is a frequently cited factorwhen explaining Israeli’s innovation success. This, however, only partly explains why so much innovation is occurring in one place.</p> <p>The United States Department of Defense (DoD) recognizes growing climate risks across its responsibilities as land manager, operator of hundreds of installations, and in its core mission to protect national security. However, DoD climate risk reduction is complicated by frequent leadership turnover among base commanders, which encourages focus on near-term challenges,</p>	<p>Mix-method research: interviews and survey</p>	<p>(SoSs), and it proposes a methodology for identifying, analyzing, and monitoring the risks that they face. The research also included semi-structured interviews.</p> <p>In Study 1, we interview a panel of six experts who are key figures in the Israeli information technology industry; In Study 2, we survey thirty MBA students, asking them about the sources of Israel’s innovation culture.</p>	<p>Theoretically, this study proposes a new look at innovation culture values. By extending previous culture of innovation analyses, this study highlights the way in which the mix of both collectivist Eastern and individualistic Western cultures values, accompanied with a combination of novelty and appropriateness of ideas, leads to exceptionally high levels of innovation. Empirically, this study informs us about the multicultural aspects that may contribute to the development of innovation clusters worldwide.</p>	<p>First, this study examines cultural factors that elicit innovation as perceived by key figures in the Israeli high-tech industry and its future managers. In the future, a richer data collection option would be to study international innovation experts working with Israeli teams. Second, future research should examine whether teams with cultural combinations (<i>i.e.</i>, Israel or USA and Singapore) indeed yield higher innovation, compared with homogenous teams, or teams with other culture combinations.</p>
<p>Garfin <i>et al.</i> (2021)</p>	<p>Study DoD’s adaptation efforts in the context of best practices currently being adopted by a growing global community of climate adaptation scientists working with a wide range of stakeholders and organizations (goal).</p>	<p>Study DoD’s adaptation efforts in the context of best practices currently being adopted by a growing global community of climate adaptation scientists working with a wide range of stakeholders and organizations (goal).</p>	<p>Qualitative case study research</p>	<p>Multi-project workshop and interviews with DoD personnel</p>	<p>The authors found that success in working with defense installations hinges on linking risks of increasing climate-related impacts to DoD’s ability to achieve its mission objectives at installations. Workshop participants offered insights into barriers to adaptation, including access to decision-makers in a hierarchical organization, leadership focus on near-term challenges, insufficient training or capacity to integrate climate information into short and long-term decisions, and rapid turnover in leadership. They also found opportunities for mainstreaming climate risk management into DoD activities, including emphasizing risks to DoD’s mission, opportunities to form symbiotic partnerships with external partners, and the potential for standardized procedures for considering physical climate risks that could be integrated across the DoD to achieve longer-term solutions to climate change challenges.</p>	<p>Whereas directives from the Pentagon are a strong motivator, integration of climate-smart strategies into day-to day practices and long-term planning processes by military and civilian employees at the installations will be needed to manage physical climate risks. Integrating top-down and bottom-up strategies, combined with the flexibility to partner and gain expertise from networks of researchers and stakeholders, will help navigate the complex terrain of DoD’s new mission to adapt to climate change.</p>



		and changing US government priorities that downplay climate risk.				
Igić <i>et al.</i> (2021)	Main hypothesis: H1: ELW has a direct positive effect on ZAV implementation.	Not identified	Quantitative. Survey	It was conducted a survey using a questionnaire given to four production plants in the Serbian military industrial complex. Almost 500 respondents participated in this survey with a response rate of over 90%.	In this article, preliminary empirical proofs for the influence of ELW on the implementation of the ZAV and OC are presented.	Future research should be improved by the inclusion of other mediating variables, e.g., work engagement, authorization, motivation and confidence.
Park and Park (2020)	Not identified	Rapid urban development and changes in the national defense environment have required civil–military coexistence plans Insufficient scientific research on financial security management necessitates the solution of the scientific task, which is to ensure the financial security of defense enterprises,	Fundamental Research	In this study, as the basic data for proceeding with the underground-type ammunition magazine construction, the effect of reducing the safety distance was analyzed.	It was concluded that research to specify design methods for underground-type ammunition magazines was urgently required to vitalize future underground-type ammunition magazine projects.	It will be necessary to apply a particular construction case in the future to verify the results of this study, and to carry out specific studies on constructability, economics, safety, and maintenance of detailed design methods.
Sydorov <i>et al.</i> (2020)	Not identified	taking into account the threats and opportunities for the development of their interaction with the environment on the basis of the development of conceptual,	Qualitative case study research	Statistical analysis, comparison, economic-mathematical and graphic methods	The article investigates the specifics of the military-industrial complex functioning in Ukraine. Theoretical analysis has shown that the development of the country’s defense industry and the state of enterprise’s financial security within this industry have a dual impact on various components of the national security system: is a realization tool of the national interests, which in turn creates opportunities for its strengthening, and it can also be a source of threats to the state’s economic security by its components due to the accumulation of internal negative elements on enterprises (insufficient development and low level of military products competitiveness, obsolescence of fixed assets at enterprises, etc), as well as due to the low ability of enterprises to respond adequately to the challenges arising from changes in external conditions and factors (disruption of sustainable cooperation, increased competition between different military products in domestic and foreign markets, etc).	Not identified



			methodological and applied components.			
Fernandes <i>et al.</i> (2020)	Not identified	Not identified	Qualitative case study research	Reports analysis	This article aims to describe the first initiative of the army in order to establish new productive arrangements involving companies, academia not only by using funding but also its intellectual property and to report its first outcomes. The pilot aimed to test this model of open innovation arenas for developing dual technologies from a very incipient stage to foster the industries' sustainable development and reduce its dependence from government funding and demands	Not identified
Silva and Quandt (2019)	How can the model of the Triple-Helix, implemented by the Brazilian Army, called SisDIA, contribute to the structure and the promotion of innovation in defense of existing habitats in the headquarters of Military Regions?	The problem is that since the year of 2016, the Brazilian Army created the Defense, Industry and Academy System (SisDIA) of Innovation, a conceptual model of the Triple-Helix, aiming to promote the development of innovations taking advantage of the Army presence in all regions of the country	Exploratory, qualitative and descriptive approach, and the case study of the Brazilian Army	Institutional documents of the Brazilian Army. Studies published at the website from the Ministry of Science, Technology Innovation and Communications (MCTIC), the International Association of Science Parks and Areas of Innovation (IASP) and the National Association of Entities that Promote Innovative Enterprises (Anprotec). Direct and participative observation.	This article intends to identify the technological parks existing in the headquarters of military regions of the Brazilian Army, with the premise that these habitats are capable of forming nuclei of governance of technological innovation. It was possible to conclude that through SisDIA and the implantation of governance nuclei of innovation in the Brazilian Army, inserted in technological parks, there will be a possibility of interaction between the Triple-Helix (government industry-academy), in a collaborative way, intending to reinforce the scientific and technological expression of the actors involved and to boost the development in social and economic dimensions according to regional potentialities.	Not identified
Coleman (2019)	Not identified	Not identified	Exploratory, qualitative and descriptive approach	Descriptive	Guantánamo is infamous as a site of extra-legal detention in the wake of 9/11; more than a single site, it is part of a web of the United States' militarization operating in the Global South. An area of the military base is now being revitalized as a new camp for climate change-related mass migration events predicted to occur throughout the Caribbean and Latin America.	Not identified
Vicente Oliva and Martinez-Sanchez (2018)	What would the difference in an actor's behaviour be as a result of the foresight intervention?	The literature examines the theoretical foundations of foresight, which generally recognises that there is a gap	The analysis is based on a content analysis of public domain Spanish Defense National Foresight Exercise, and a study directed to analyse the impact on defense	Technology roadmaps	Foresight studies on the defense and security environment uses hybrid methodologies, but rarely involve all the stakeholders, and specially the citizens. The authors place a particular emphasis on the impact of these defense and security foresight studies, and following policies to increase the competitiveness and advanced technologies in the future. The analysis of the Spanish contractors allows an evaluation of the roadmaps as a policy instrument for the next defense industry. The main challenges for the next exercises in the European countries are to increase the interest in the firms' intelligence systems, and the	Future studies about the impact of foresight exercises in the defense sector should incorporate a wider focus ( <i>i.e.</i> , citizens, research centres) because they influence and have implications for strategic decision-making in science and technology systems. Therefore, the impact of TRs should be larger than we have found and could even go beyond the S&D industry. A longitudinal study could be useful to analyse the impact of every phase of the study and improve the



		between practice and theory in the field	technological and industrial base.		participation and representation of citizens as a way to guarantee their rights. Therefore, a technology roadmap must be complemented with other more participative foresight methods.	dissemination and learning phase that support new policy instruments; the efficiency of the exercise could even be measured in economic terms for some of the agents of the national system, such as firms
Bradshaw and Connolly (2016)	Can Russia afford to continue to strengthen its military capability in the face of falling oil and gas export revenues, economic recession, and growing social demands on the federal budget? How do the changes in the global oil and gas industry – and upheavals in Russia’s own oil and gas industry – affect Russia’s ability to undertake the rearmament that has underpinned its more muscular role in the world? What might happen next: détente revisited, or a new Cold War?	The leaders of today’s Russia face a twenty-first-century version of this dilemma, weighing the trade-off between spending on guns or butter.	Qualitative case study research	Descriptive	It is clear that developments in the oil and gas industry – both at the global level and in Russia – are imposing financial constraints on the Kremlin and will likely continue to do so in the near term. While it is evident that the Russian leadership continues to assign a great deal of importance to enhancing its military capabilities – and had done so well before the crisis in Ukraine – it is equally clear that tough choices need to be made if this revitalization of capabilities is to continue at its current pace.	Not identified
Hinwood <i>et al.</i> (2015)	Not identified	Most studies of metals exposure focus on the heavy metals. There are many other metals (the transition, alkali and alkaline earth metals in particular) in common use in electronics, defense industries, emitted via combustion and which are naturally present in the environment, that have received limited attention in	Qualitative case study research	The authors analysed samples of whole blood (172), urine (173) and drinking water (172) for antimony, beryllium, bismuth, cesium, gallium, rubidium, silver, strontium, thallium, thorium and vanadium using ICPMS.	In general most metals concentrations were low and below the analytical limit of detection with some high concentrations observed. Few factors examined in regression models were shown to influence biological metals concentrations and explained little of the variation.	Further study is required to establish the source of metals exposures at the high end of the ranges of concentrations measured and the potential for any adverse health impacts in children.



				terms of human exposure.			
Ghorshi Nezhad <i>et al.</i> (2015)	Not identified	Not identified	Mixed methods	Hybrid methods in multicriteria decision-making (HMCDDM)	The Multiple Criteria Decision Making perspective can be considered as a powerful framework and methodology in this way. This perspective can divide the topic into sub-topics and make the decision-making process easier. The SWARA method has a powerful and logical perspective for decision and policy-making because priorities have different dimensions, such as politics, culture, and so on. In this study SWARA is applied in the process of decision-making for evaluating the weights and priorities of criteria. WASPAS is a new methodology that is very reliable for calculations. In this study, WASPAS is applied to evaluate and rank alternatives.		Planning is presented based on the priority of results. Investing priorities should be considered based on the results of Table 15 (see article). This new framework can be considered as a framework for future and similar research
Fiott (2014)	Is Europe's defense greening best characterized by a process of regulation-defined as policy and legal initiatives and processes designed to steer decisions, in this case in the direction of green behavior?	There is little evidence to suggest that the defense sector in Europe has taken a holistic approach to the green agenda, but neither can that sector be considered as following only a "ceremonial" approach.	Mix-method research Qualitative sources - primary information sources: <i>e.g.</i> , official documents. Quantitative sources: <i>e.g.</i> , data from the british MoD and EDA Qualitative sources: <i>e.g.</i> , interviews	This article relies mainly on an examination of key primary information sources, such as government and EU policy documents, and a host of secondary sources that relate to the greening of organizations. The article nevertheless draws on quantitative data provided by the British MoD, the EDA, and a range of European-based defense firms where necessary and available to illustrate progress and failure. Eight of the interviews conducted are directly cited in this article.	This article argues that the defense sector in Europe is far from being a holistic green actor		Not identified
[No author name available] (2014)	Not identified	Not identified	Qualitative case study research	Descriptive	The increasing limitations that the environment is placing on organizations worldwide are changing the skills that employees require. IEMA has been calling for all employees – at every level of responsibility, across all areas of business and industry – to be armed with environmental knowledge.		Not identified
Emmanuel-Ebikake <i>et al.</i> (2014)	Not identified	Shepherd and Gunter (2006) identified a gap in SCM literature where limited reflection had been one on the important subject of	Quantitative research	The research employs a case study approach to identify a research gap in the area of supplier performance measurement and proposes five dimensions to assess supplier sustainability from the review of literature and industry practice while employing a systematic	The sustainability measures, dimensions and improvement actions developed were validated with industrial experts from three defense companies and implemented as a sustainability system. A case study was applied and the results were generated. The paper offers managerial implications about the need to consider the survivability of suppliers in the long term, especially in the current economic climate and think about mitigation strategies to enable economic sustainability.		Future research could include further case study application and application of dimensions and measures to other industries.



				performance measurement.		approach to generate measures for each dimension with suggested actions to improve sustainability.		
King and Goodman (2011)	Not identified	Not identified	Qualitative research			The article frames the long-term course for policy decision-making at the highest levels.		The reports demonstrate that climate change and energy are now mainstream elements of national security planning, and can be assessed within the frameworks used to evaluate other threats, risks, and responses. However, the exact magnitude of the threat posed by climate change is difficult to calibrate in part because the language used by scientists to predict uncertainty and the confidence levels of judgments is not sufficiently clear. The defense community has a vast amount of experience exploring and dealing with uncertainty
Saulters <i>et al.</i> (2010)	Not identified	Not identified	Systems-based methodologies			Accordingly, a proactive and holistic approach can facilitate efficient research, design, testing, evaluation, and fielding for novel and off-the shelf products, thereby assisting developers, end users, and other diverse stakeholders in better understanding tradeoffs in the defense industry and beyond. By prioritizing mechanisms such as strategic life-cycle environmental assessments (LCEA); programmatic environment, safety, and occupational health evaluations (PESHE); health hazard assessments (HHA); and other innovative platforms and studies early within systems engineering, various nonlethal military technologies have been successfully developed and deployed.		These efforts provide a framework for addressing complex environment, safety, and occupational health risks that affect personnel, infrastructure, property, socioeconomic, and natural/cultural resources.  This paper highlights the Urban Operations Laboratory process utilized for inclusive and transformative environmental analysis, which can translate into advantages and progress toward sustainable systems.
Jan and Chen (2005)	Not identified		Qualitative research	The development of an industrial system is a complex and dynamic process. In developing countries,			Descriptive	This study discusses the viewpoints of ecological systems and system dynamics to summarize the analysis of the development of Taiwan's automobile, semiconductor, and national defense industries. In addition, an evolutionary perspective is used to examine the development of the information technology and semiconductor industries. The results show that different systems viewpoint provides different insights into industrial development.
								Scientists trying to better describe the effects of climate change may be able to draw lessons from the defense community's approach to uncertainty including how to better communicate findings to wide audiences including policy-makers.  An integrated, comprehensive, multidisciplinary, and iterative analyses involving flexible groups of specialists/subject matter experts can be applied at various spatiotemporal scales in support of collaborations.  Therefore, more diverse systems approaches are needed to further our understanding of the development of industrial systems.



					industrial development is even more complicated because it involves the interactions of domestic firms and multinational corporations (MNCs), the role of the government, and the development of technology.	
Barros (2005)	What are the reasons for a defense enterprise to be technically inefficient and to work below the production function?	Not identified	Quantitative research	Not identified	The article proposed a simple framework for the evaluation of defense-sector companies and the rationalisation of their operational activities.	The author propose a policy revision to enforce efficiency, based on a governance environment framework.
Barros (2004)	What is the motivation of a government to fund inefficient public enterprises?  what is the motivation for the government not to oversee properly the performance of a public enterprise?	Not identified	Nonparametric method in operations research and economics	Data envelopment analysis (DEA)	The article has proposed a simple framework for the evaluation of defense-sector companies and the rationalization of their operational activities.  The general conclusion is that an organizational governance environment with accountability, transparency and efficiency incentives, which explicitly oblige the defense sector companies to achieve efficiency in their operational activities, is needed to overcome the deficits in technical and allocative efficiency observed in the companies over the period analyzed.	The banning of military personnel from the management of defense enterprises, in addition to the privatization and outsourcing are also recommended as policies to improve the economic efficiency of this industry in Portugal, if it is to survive.
Sandström (2004)	The question comes down to how a defense organization, such as FMV, can move into a non-defense mode, in this case in regard to greening	Civil organizations are also ahead of the military'. Swedish Defense Material Administration (FMV) was therefore moving to close this gap, but the process housed two areas of tensions.	Qualitative case study research	Interviews	FMV is particularly influenced by an industry-driven institutionalization of greening, but that there also are signs of countermoves and thereby spaces in which reflexive dialogues on the taken-for-granted approach to greening might occur.	By following others' approaches to environmental policy-making, does the uniqueness of one's own organization's type of process, environmental impact, organizational culture and phase in life become peripheral or even suppressed? Also, what does this say about the future developments of organizational approaches to greening? Are the forces of industry too strong to allow for alternatives to develop?



Kapstein (2002)	Not identified	Weapons procurement decisions only provide a single case study with respect to alliance relations- hardly a complete view of the political landscape.	Qualitative case study research	Descriptive	Ever since its inception, NATO has striven to promote the 'rationalisation, standardisation and inter-operability' of alliance weaponry. From this defense-industrial perspective, the alliance has made great strides over the past decade. For its part, the United States has undertaken a major reform of its technology-transfer bureaucracy, with the aim of promoting more transatlantic weapons collaboration. Alongside that development, the Europeans have engaged in a radical restructuring of their defense industries, making them bigger and more competitive.	These changes suggest continuing efforts on each side of the Atlantic to maintain if not strengthen their security relationship.
Bates and Kukalis (1998)	But how are their suppliers performing and what strategies are they pursuing?	The aerospace/defense industry is in decline. Revenues and profits are falling and experts believe the decline will last into the foreseeable future. The prime contractors, are pursuing classic large firm strategies for declining industries, e.g., mergers, twinning, diversification, etc.	Qualitative case study research	Descriptive	Two-thirds of the second-tier firms had suffered significant revenue declines in the four year period. It seems logical to expect these supplier firms would develop strategies appropriate to declining industries. Generally, the firms are doing just that. They are pursuing cost reduction/containment strategies and they are developing strategic thrusts to enter or expand their revenues from commercial markets. Of the four most commonly used strategies, two involve either domestic or international defense markets and one involves existing defense products. Only one strategy did not incorporate any involvement with the defense industry. An examination of the strategic planning systems reveals little or no changes have been made. The firms enter commercial markets with high hopes and a realistic understanding of the obstacles they face, but they still regard the aerospace/defense industry, as their primary source of revenue.	Not identified
Kapstein (1995)	Why don't market mechanisms suffice to reallocate resources as government outlays change?	The regional impact of the changes in federal budgetary expenditures has received little attention from scholars of the former Soviet Union.	Qualitative case study research	Descriptive	The article argues that the donor nations should instead strive to provide a "package" of assistance to defense-dependent regions, taking into account such issues as employment generation and the development of small and medium enterprises, the quality of telecommunications, infrastructure, and the environment and the ability of local governments to finance and manage the social assets of restructured enterprises.	Not identified



## SM 6 – General information of selected articles

Study	Title	Source Title	Vol	Issue	Start Page	End Page	Cited
Reis <i>et al.</i> (2022)	Defense industries and open innovation: ways to increase military capabilities of the Portuguese ground forces	Defense Studies	22	3	354	377	
Gouvea <i>et al.</i> (2021)	China's diversification strategy in Latin American and African markets: Defense software and hardware exports	Thunderbird International Business Review	63	4	463	475	
Erdağ (2021)	Security Environment and Military Spending of Turkey in the 2000s	Contemporary Review of the Middle East	8	1	120	139	1
Kordova and Fridkin (2021)	Risk management for defense SoS in a complex, dynamic environment	Sustainability (Switzerland)	13	4	1789	1	
Yeshua-Katz and Efrat-Treister (2021)	'Together in the tech trenches': a view of Israel's innovation culture	Innovation: Organization and Management	23	3	337	353	1
Garfin <i>et al.</i> (2021)	A new mission: Mainstreaming climate adaptation in the US Department of Defense	Climate Services	22	100230			
Igić <i>et al.</i> (2021)	The relationship between ethical leadership, organizational commitment and Zero Accident Vision implementation in the defense industry	International Journal of Occupational Safety and Ergonomics	27	4	1076	1086	1
Park and Park (2020)	Effect of underground-type ammunition magazine construction in respect of civil and military coexistence	Sustainability (Switzerland)	12	21	9285	1	
Sydorov <i>et al.</i> (2020)	Financial Security Management of Enterprises Operating in the Defense Industry	Journal of Security and Sustainability Issues	9	4	1483	1495	
Fernandes <i>et al.</i> (2020)	The triple helix approach in the defense industry: A case study at the Brazilian Army	World Review of Science, Technology and Sustainable Development	16	1	22	43	1
Silva and Quandt (2019)	Defense system, industry and academy: The conceptual model of innovation of the brazilian army	Journal of Technology Management and Innovation	14	1	53	62	2
Coleman (2019)	El Sur También Existe: Imagining futures	Cultural Dynamics	31	4	365	374	
Vicente Oliva and Martinez-Sanchez (2018)	Technology roadmapping in security and defense foresight	Foresight	20	6	635	647	3
Bradshaw and Connolly (2016)	Barrels and bullets: The geostrategic significance of Russia's oil and gas exports	Bulletin of the Atomic Scientists	72	3	156	164	7
Hinwood <i>et al.</i> (2015)	Maternal exposure to alkali, alkali earth, transition and other metals: Concentrations and predictors of exposure	Environmental Pollution	204	256	263		
Ghorshi Nezhad <i>et al.</i> (2015)	Planning the priority of high tech industries based on SWARA-WASPAS methodology: The case of the nanotechnology industry in Iran	Economic Research-Ekonomiska Istrazivanja	28	1	1111	1137	38
Fiott (2014)	Reducing the Environmental Footprint? Competition and Regulation in the Greening of Europe's Defense Sector	Organization and Environment	27	3	263	278	10



[No author name available] (2014)	BAE Systems takes environmental training to the top: Senior executives learn how to integrate green issues into their everyday functions	Human Resource Management International Digest	22	1	7	10	1
Emmanuel-Ebikake <i>et al.</i> (2014)	Supplier sustainability assessment for the UK defense industry	International Journal of Productivity and Performance Management	63	8	968	990	3
King and Goodman (2011)	Defense community perspectives on uncertainty and confidence judgments	Climatic Change	108	4	803	809	5
Saulters <i>et al.</i> (2010)	Enhancing technology development through integrated environmental analysis: Toward sustainable nonlethal military systems	Integrated Environmental Assessment and Management	6	2	281	286	2
Jan and Chen (2005)	Systems approaches for the industrial development of a developing country	Systemic Practice and Action Research	18	4	365	377	17
Barros (2005)	Governance and incentive regulation in defense industry enterprises: A case study	European Journal of Law and Economics	20	1	87	97	3
Barros (2004)	Measuring performance in defense-sector companies in a small NATO member country	Journal of Economic Studies	31	2	112	128	38
Sandström (2004)	Greening the Swedish Defense Material Administration - A case study on the force of industry in environmental policy-making	European Environment: Environmental Policy and Governance	14	6	356	367	1
Kapstein (2002)	Allies and armaments	Survival	44	2	141	155	16
Bates and Kukalis (1998)	The endgame in aerospace: a disaster waiting to happen?	Long Range Planning	31	4	615	622	1
Kapstein (1995)	The economic transition in defense- dependent regions of russia	Defense and Peace Economics	6	3	253	261	5

