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Green Transformation of Defense Industry SME's in Türkiye and the World

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ABSTRACT

This study examines the green transformation of Türkiye's defense industry within the environmental framework sustainability, economic resilience, and technological autonomy. It evaluates Türkiye's recent progress in sustainability production, energy efficiency, and carbon management while providing a comparative analysis with European and NATO countries. Findings indicate that the green transformation has become a strategic necessity in the defense sector; however, structural adaptation within SME- level supply chains remains limited. Although the Presidency of Defense Industries (SSB) has established an essential foundation through sustainable production programs, there is still a need to strengthen financial incentives, institutional standards, and R&D-driven innovation The study proposes a comprehensive strategy integrating green finance, education, digital twin technologies, and circular economy practices to enhance environmental performance and competitiveness in the Turkish defense industry.

Keywords *: Green transformation, sustainable defense, circular economy, SMEs, energy efficiency, carbon management.*

1. INTRODUCTION

In addition to being a fundamental component of a country's national security capacity, the defense industry also has a decisive influence on economic development, technological innovation, and foreign policy instruments (Brzoska, 2019; Bitzinger, 2020). Furthermore, the defense industry has one of the highest carbon footprints among industrial sectors in terms of environmental impacts due to its high energy consumption, complex supply chains, and the chemical, metallic, and electronic waste generated during production processes (SSB, 2022; OECD, 2021). This necessitates that environmental impacts be addressed not only within the framework of environmental policies but also become an integral part of national security strategies (UNEP, 2022; NATO, 2023).

In recent years, global climate change, the rapid depletion of natural resources, and the degradation of ecosystems have made the adoption of sustainable production and environmental management approaches a necessity in the defense industry. In this context, the concept of "green transformation" encompasses not only environmentally friendly production techniques but also the integration of energy efficiency, lifecycle management, waste reduction, and circular economy principles into the sector (EU Commission, 2020; TÜBİTAK, 2021). Green transformation is seen as a critical tool for ensuring both environmental and economic sustainability in the defense industry.

SMEs, in particular, play a strategic role in the defense industry supply chain in terms of both flexibility and innovative capacity. These companies' adaptation to the green transformation is crucial not only for reducing carbon emissions, but also for reducing energy costs, streamlining production processes, gaining competitive advantage, and developing production systems compliant with international standards (EDA, 2020; TÜSİAD, 2021; ISO, 2023). The environmental performance of SMEs is directly linked to the sustainability goals of major system integrators and prime contractors; therefore, their transformation is critical to sectoral success.

From Türkiye's perspective, the green transformation of the defense industry is directly linked to the country's strategic autonomy goal. Developing domestic and national technologies in an environmentally friendly manner, reducing energy dependence, and considering environmental criteria in international defense collaborations supports a long-term vision in both economic and security dimensions (SSB, 2022; DPT, 2020). Within this framework, the primary objective of this study is to analyze the green transformation processes of defense industry SMEs in Türkiye and globally, to reveal the successes and shortcomings of these practices, to assess the role of SMEs in the transformation, and to develop policy recommendations for a sustainable defense ecosystem.

It is also emphasized that green transformation in the defense industry is not only an environmental imperative, but also an economic and strategic one. Carbon border taxes, rising energy costs, and international regulations, particularly in global supply chains, make the transition to environmentally friendly production not a choice but a necessity for SMEs (OECD, 2023; UNIDO, 2022). Therefore, this study aims to provide a comprehensive analysis that considers not only environmental impacts but also economic sustainability and national security perspectives.

1.1. Research Questions

This study aims to examine the dynamics of sustainable transformation in the defense industry at both national and international levels. The following fundamental research questions guide the study:

1. What are the structural, financial and technological obstacles to the green transformation of defense industry SMEs?
2. What is the current stage of green transformation practices in the Turkish defense industry, and how do sectoral strategy documents guide this transformation?

3. What policies and institutional practices stand out for the green transformation of the defense industry at the international level (especially in the EU, NATO and the USA)?
4. How can environmental sustainability goals in the defense industry be balanced with national security and economic development goals?

These questions are analyzed throughout the article, drawing on both theoretical literature and sectoral data. The Turkish case is evaluated in comparison with initiatives such as the European Defence Agency (EDA), the NATO Green Defence Programme, and the European Union Green Deal (EDA, 2021; NATO, 2023; EU, 2020).

1.2. Literature and Conceptual Framework

The concept of green transformation has become central to industrial policies, energy security, and sustainable development strategies in recent years (UNDP, 2021; IEA, 2023). The literature generally examines four key dimensions: environmental sustainability, energy efficiency, resource circularity, and carbon reduction (NATO, 2014; EU, 2020; ISO, 2023). Academic studies specific to the defense industry detail technical innovations, institutional structures, and policy instruments aimed at reducing the environmental impact of production processes (Bitzinger, 2020; SSB, 2022).

Technical Dimension: Integration of renewable energy sources, use of low-carbon materials, modular system design, and incorporation of recyclable components into the production cycle are gaining prominence in defense production (TÜBİTAK, 2021; ISO, 2023). For example, environmental certification (EcoDesign, ISO 14001) processes have been made mandatory in the US and EU defense procurement systems (DoD, 2021; EDA, 2020). Furthermore, advanced simulation and digital twin technologies reduce environmental impacts in the production process by optimizing energy and material usage (Deloitte, 2023).

Institutional Dimension: Establishing in-house sustainability departments, integrating carbon footprint measurement systems, and adopting green procurement principles constitute the cornerstones of institutional transformation (TÜSİAD, 2021; OECD, 2021). In Türkiye, major defense industry players such as ASELSAN, TUSAŞ, and ROKETSAN have begun implementing ISO 50001 Energy Management and ISO 14064 Carbon Management standards in recent years (SSB, 2022). These practices serve as a direct example for SMEs to achieve more environmentally friendly and efficient production in their supply chains.

Policy Dimension: The European Union 's Green Deal Green Deal), NATO's " Green The " Defense " strategy and the United Nations' Sustainable Development Goals (UN SDGs) offer policy and financial support mechanisms to encourage environmentally friendly production in the defense industry (EU, 2020; NATO, 2023; UNEP, 2022). These policies include dedicated funds for energy transition, carbon taxation, and clean technology R& D (Öz, 2022).

In the Turkish context, SMEs, in particular, have the potential to adapt relatively quickly to the green transformation process thanks to their modular and flexible production structures (TÜBİTAK, 2021). The EU harmonization process has encouraged the internationalization of industrial standards and facilitated the integration of SMEs into green supply chains (TÜSİAD, 2021; SSB, 2022). However, lack of financing, technical knowledge, and certification costs are cited as the most significant obstacles to this process (OECD, 2021; EDA, 2021).

2. METHOD

This study, based on a qualitative research approach, aims to examine the green transformation processes of SMEs in the Turkish and global defense industry within a multidimensional framework. The research is not limited to descriptive analysis but also evaluates the impact of these practices and their level of compatibility with the international context through comparative case studies. In this context, the green transformation practices of SMEs operating in the Turkish defense industry were systematically analyzed through corporate strategies and national and international policy documents (Yıldırım & Şimşek, 2021; Creswell, 2018).

2.1. Research Design

The research design is structured to comprehensively present the current status of green transformation in the defense industry, its implementation levels, and the obstacles encountered. The design consists of three main phases:

Literature Review: National and internationally published reports, academic articles, strategic documents, and environmental sustainability policies related to the defense industry were systematically reviewed (OECD, 2021; NATO, 2020; EDA, 2022). The literature review covers studies from 2010 to 2024 and focuses specifically on green defense technologies, circular economy, carbon reduction, and sustainable production. Furthermore, gaps in the literature were identified and compared with the practices of SMEs in Türkiye.

Case Study : Large Turkish defense industry companies such as ASELSAN, ROKETSAN, TUSAŞ, and MKE, along with their supplier SMEs, were selected. These companies' sustainability reports, environmental performance indicators, and corporate strategies were evaluated in detail using content analysis (ASELSAN, 2023; ROKETSAN, 2022; MKE, 2023). Within the scope of the case study, the companies' energy efficiency practices in their production processes, waste management, recycling practices, and supply chain sustainability were examined in detail (Öz, 2025).

3. Policy Analysis: European Union Green Deal Green Deal), NATO Green Regulatory frameworks such as the Defence Framework and Türkiye's National Green Deal Action Plan have been comparatively examined (European Commission, 2020; NATO, 2022; Republic of Türkiye Ministry of Trade, 2021). This analysis aimed to reveal the extent to which Turkish defense industry SMEs comply with international practices and the policy gaps that will improve their environmental performance.

2.2. Data Collection Techniques

The study prioritized secondary data over primary data, but a limited number of semi-structured expert interviews were conducted to validate the qualitative data. The interviews were conducted with a total of 10 experts from environmental management, strategic planning, and sustainability units in defense industry companies. The interviews were analyzed using thematic analysis in accordance with the purpose of the research (Braun & Clarke, 2019).

The collected data is classified into three main categories:

- **Corporate data:** Company reports, environmental performance indicators, ISO 14001 and ISO 50001 certification records, energy consumption data.
- **Policy documents:** Official strategies, national plans, NATO and EU reports, environmental regulations and action plans.
- **Academic literature:** Peer-reviewed articles, theses, sector analyses and sustainability reports.

2.3. Data Analysis Method

Content analysis, thematic coding, and comparative evaluation techniques were applied in conjunction during the data analysis process. The analysis identified prominent concepts in the texts (e.g., "carbon reduction," "sustainable procurement," "environmental innovation," "energy efficiency"), and these themes were then categorized using NVivo software (Silver & Lewins, 2014).

National practices were evaluated using comparative analysis with international examples, thus analyzing Türkiye's defense industry sustainability capacity in a comparative context with European and NATO member countries (EDA, 2021; OECD, 2020). Furthermore, during the case study process, performance differences and transformation successes were examined in detail based on companies' production scale, technological capacity, and environmental performance indicators.

2.4. Validity and Reliability

triangulation) approach was adopted to enhance the validity of the research. Academic literature, field data, and institutional documents were compared and analyzed (Patton, 2015). Furthermore, expert verification was conducted in interpreting the findings; three academics and two industry representatives were consulted to ensure content consistency. This process increased the reliability and reproducibility of the data.
expert validation is required in interpreting the findings. validation) was conducted. During this process, three academics and two industry representatives assessed the reliability of the content and comments. The thematic categories and coding process used in data analysis were reviewed by an independent researcher to increase the reliability of the analysis.

2.5. Ethical Principles

The study fully complied with ethical principles. Informed consent was obtained from all experts participating in the interviews, personal data was anonymized, and used solely for scientific purposes. Furthermore, data confidentiality and publication ethics standards set by national ethics committees were adhered to (APA, 2020).

3. FINDINGS AND DISCUSSION

This section provides a detailed overview of the current state of the green transformation in the Turkish defense industry, international approaches, and the role of SMEs in the transformation process. The findings are presented through an analysis of data obtained from literature and policy documents, as well as sectoral practices. The analysis is conducted in three dimensions: global trends, the level of national strategic alignment, and the environmental performance capacity of defense industry SMEs.

3.1. Green Transformation Trends in the Defense Industry

Over the past decade, there has been a clear trend toward aligning defense industries with environmental sustainability goals on a global scale. The European Union, the United States, and NATO member states, in particular, have developed comprehensive strategies to reduce the carbon footprint of defense activities, optimize natural resource use, and minimize environmental risks (NATO, 2022; EDA, 2021).

In this context, "Green Defense", "Sustainable Armed Forces" and "Defense Energy Initiatives" such as the Transition Program promote renewable energy use, energy efficiency, and waste management policies across a wide spectrum, from military operations to the supply chain (OECD, 2023; RAND Corporation, 2020). Countries that have adopted carbon-neutral targets in defense industry production have also mandated environmental criteria (green procurement) in public procurement.

In Türkiye, in the post-2020 period, green transformation policies are increasingly being considered within the framework of the National Technology Initiative, the Green Deal Action Plan, and the Sustainable Production Program implemented by the Presidency of Defense Industries (SSB) (SSB, 2022; Republic of Türkiye Ministry of Commerce, 2021). However, this transformation process is still in its early stages, and structural deficiencies remain, particularly in SME-scale supply chains.

Table 1. Outlines of Green Transformation Policies in the Turkish Defense Industry

Policy Document / Program	Executing Institution	Aim	Target Year	Focus Areas
Green Deal Action Plan (2021)	Ministry of Commerce	Compliance with the EU Green Deal	2030	Carbon reduction, green procurement

Policy Document / Program	**Executing Institution**	**Aim**	**Target Year**	**Focus Areas**
SSB Sustainable Production Program (2022)	Presidency of Defense Industries	Environmentally friendly transformation in defense production	2035	Energy efficiency, recycling
TÜBİTAK Green R &D Supports	TUBITAK	Environmental innovation in SMEs	Continually	Eco-innovation, circular production
NATO Green Defense Framework (2022)	NATO	Green defense infrastructure in member countries	2050	Carbon neutrality, renewable energy

(SSB, 2022; Republic of Türkiye Ministry of Trade, 2021; NATO, 2022; TUBITAK, 2023).

Table 1, summarizes the key axes of green transformation policies implemented in the Turkish defense industry. These policies focus specifically on areas such as energy efficiency, reducing the carbon footprint, implementing environmental management systems, and establishing sustainable supply chains. Environmental sustainability principles highlighted in the Presidency of Defense Industries' 2022 Strategy Document include transforming production processes with low-carbon technologies, adopting a circular economy approach to waste management, and expanding standards such as ISO 50001 and ISO 14064. Furthermore, in line with the priorities outlined by the European Defense Agency (EDA) and Türkiye's Green Deal Action Plan, traceability and reportability of environmental performance are being strengthened within the sector.

3.2. Comparative Analysis of Turkish and International Practices

A comparative analysis revealed significant differences between the green defense policies of European and NATO countries and those implemented in Türkiye. While European countries made environmental standards mandatory in defense procurement after 2015, this process is proceeding on a voluntary basis in Türkiye. Furthermore, in Western countries, carbon emission measurement, environmental impact assessment, and reporting processes have been integrated into institutional systems (EDA, 2022).

Table 2. Comparative Analysis of Green Defense Policies in Türkiye and International (European/NATO) Countries

Dimension / Criterion	Türkiye	Europe and NATO Countries	Explanation
Policy Approach	Volunteer-based practices, SSB in the guidance role	Mandatory environmental standards and legislation-based system	In Europe, environmental conditions in defense procurement after 2015 have been tied to the legal framework.
Environmental Standards	ISO 14001, ISO 50001 certification is implemented to a limited extent	ISO standards are mandatory and integrated into supply chain audits	The European Defence Agency (EDA) monitors environmental certification processes.
Carbon Emission Measurement	Partial measurements are available on an institutional basis	Reporting systems at national level (CO_2 monitoring obligation)	NATO countries have integrated carbon footprint into their defence planning.

Dimension / Criterion	Türkiye	Europe and NATO Countries	Explanation
Environmental Impact Assessment (EIA)	Limited application on a project basis	Systematic and legal obligation in defense projects	In European countries, an EIA report is a prerequisite for procurement.
Reporting and Transparency	Voluntary sustainability reports	Mandatory annual sustainability and carbon reporting	There is an obligation of transparency within the framework of the EDA and EU directives.
Corporate Integration	Environmental management units are newly formed	Institutional units exist in defense ministries and procurement agencies	In NATO countries, environment and climate units are included in the strategic planning process.

(EDA, 2022; SSB, 2023; NATO, 2023; European Commission, 2021).

Table 2, provides a comparative analysis of the green defense policies of Türkiye and European and NATO countries. The analysis shows that environmental sustainability principles are integrated into the defense supply chain as a legal obligation in European countries, while in Türkiye, these processes are largely voluntary. Carbon emission measurement, environmental impact assessment, and sustainability reporting have been integrated into institutional systems in European and NATO countries (EDA, 2022; NATO, 2023). In Türkiye, however, environmental standards and reporting mechanisms are still in the institutional stage of maturation. This suggests that Türkiye needs to strengthen strategic policy alignment and institutional capacity in its green defense transformation (SSB, 2023; European Commission, 2021).

In Türkiye, most defense industry SMEs are in the process of transitioning to environmental management systems such as ISO 14001 or ISO 50001. As of 2024, only 37% of the 450 SMEs registered with the SSB held these certifications (SSB, 2024). This demonstrates that while strategic awareness of the green transformation is improving, institutional capacity gaps persist during the implementation phase.

the sustainable ecosystemstructure of the green transformation in the defense industry. The relationship between government policies (high-level governance), prime contractors (e.g., ASELSAN, TUSAŞ), supplier SMEs, and research institutions is modeled based on the principles of energy efficiency and the circular economy.

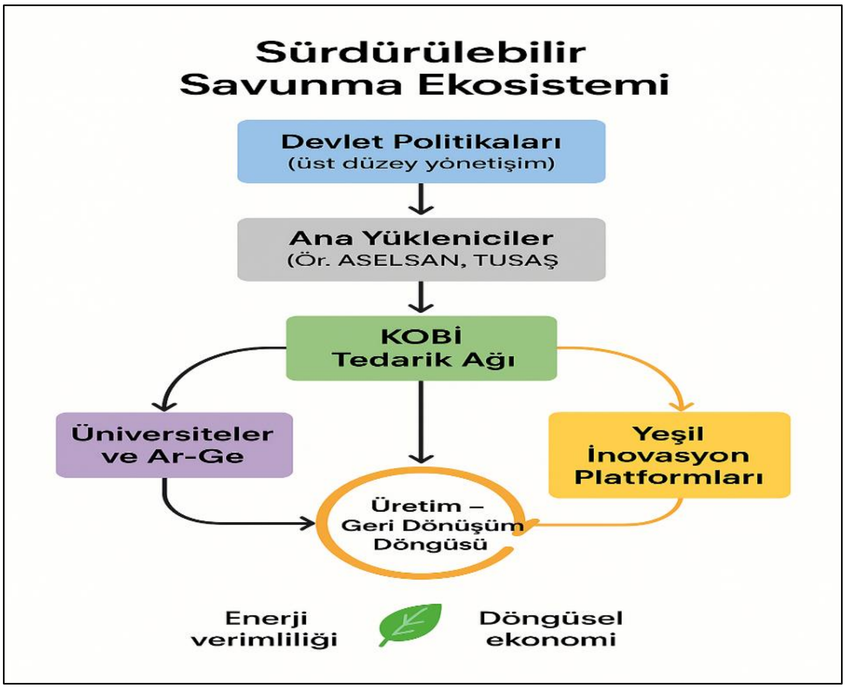

Figure 1. Sustainable Defense Ecosystem **(**Önder Savunma, 2023; STM, 2023).

Figure 1, illustrates the multilayered structure of the sustainable defense ecosystem and the interactions among its key components. The diagram addresses coordination among government agencies, prime contractors, supplier SMEs, research and development centers, and academic institutions within the framework of environmental, economic, and technological sustainability principles. Energy efficiency, a circular economy, carbon footprint reduction, and green supply chain practices constitute the fundamental dynamics of this ecosystem. This structure demonstrates that sustainability goals in the defense industry are not limited to the environmental dimension but also require a holistic approach in terms of innovative production processes, resource efficiency, and long-term strategic resilience of a "Sustainable Defense Ecosystem" refers to shaping the defense industry in line with the principles of environmental, economic, and technological sustainability. This approach aims to reduce the defense industry's environmental impact, use resources efficiently, and ensure long-term economic sustainability. For example, it is stated that Önder Defense places economic sustainability at the center of its activities in line with the principles of sustainable development and aims for sustainable growth by increasing resource efficiency, strengthening the domestic supply chain, and developing long-term financial strategies. (Onder Defense, 2023; STM, 2023).

In addition, it is stated that STM adopts a sustainability-oriented approach in the defense industry and, with its innovative perspective, sees its business partners not only as suppliers but also as strategic partners of the defense industry (STM, 2023).

In this context, the sustainable defense ecosystem is a strategic approach that includes elements such as reducing environmental impacts, resource efficiency, encouraging domestic production and ensuring long-term economic sustainability.

A sustainable defense ecosystem is a holistic approach that protects a country's security and defense capacity over the long term, optimizes resource utilization, and considers environmental, economic, and technological balances. This ecosystem aims to increase resilience in the defense sector by developing domestic and national production capabilities, utilizing renewable and efficient resources, continuously supporting R&D investments, and strengthening strategic collaborations. At the same time, a sustainable defense ecosystem minimizes the environmental and societal impacts of security policies by increasing technological independence and competencies, and supports strategic autonomy and innovation while preserving a country's defense capacity for the future.

3.3. The Role of SMEs in the Transformation Process and Obstacles

In the defense industry ecosystem, SMEs play a critical role in the supply chain of prime contractors. However, many of these businesses have limited access to capital and technology to finance green transformation investments (KOSGEB, 2023). Furthermore, in SMEs with low R&D capacity, green production awareness is often project-based and not integrated into long-term strategies.

In the defense industry, SMEs are a critical production link between system integrators and prime contractors. Their greatest advantage in terms of environmental sustainability is their flexible production structure and innovative adaptability (TÜSİAD, 2021). However, these companies' inadequacies in financing, technology access, and green certification processes limit the pace of transformation (OECD, 2021; EBRD, 2022).

In particular, the carbon border tax (Carbon Border Adjustment The implementation of the (CBAM) Mechanism has increased competitive pressure for Turkish SMEs engaged in defense industry exports (OECD, 2023). This demonstrates that the transition to environmentally friendly production technologies has become not only an environmental but also an economic imperative.

In this context, the main obstacles that stand out in the transformation process of defense industry SMEs in Türkiye are:

- **Lack of Financing:** The initial costs of switching to green technologies are high and incentive mechanisms are inadequate. High investment costs for carbon measurement systems, green energy infrastructure and waste management facilities (UNIDO, 2022).
- **Knowledge and Training Gap:** Lack of technical knowledge regarding environmental management systems is common.

- **R& D Integration Problem: Green R&** D applications find limited space in defense projects.
- **Policy Incompatibility:** There is no full harmony between current legal regulations and international standards.
- **Lack of Institutional Capacity:** Lack of expert personnel in sustainability reporting, environmental risk analysis and carbon accounting (Eren & Gür, 2020).
- **Regulatory Compliance Issues:** Uncertainty and legislative confusion regarding the technical criteria required for full compliance with EU Green Deal standards (European Green Deal Commission, 2020).

Table 3. Obstacles and Opportunities in the Green Transformation of Turkish Defense Industry SMEs

Dimension	Main Obstacles	Emerging Opportunities
Financial	High investment costs, limited access to credit	Green finance funds, EU-supported grant programs
Technological	Lack of renewable energy infrastructure	Technology transfer through ASELSAN and TUSAŞ collaborations
Institutional	Inadequacy of environmental management units	SSB's Green Procurement Framework Plan
Strategic	Short-term profitability-oriented production approach	Adopting long-term carbon neutrality targets

(Defense Industry Sustainability Report, 2022)

Table 3, summarizes the main obstacles faced by Turkish defense industry SMEs in the green transformation process and the opportunities they can address by dimension. From a financial perspective, high investment costs and limited access to credit stand out as key factors limiting SMEs' transition to environmentally friendly production; however, EU-supported grants and green finance funds offer the opportunity to overcome these obstacles. From a technological perspective, the lack of renewable energy infrastructure limits companies' environmental performance, while technology transfer with major defense industry players such as ASELSAN and TUSAŞ creates opportunities. At an institutional level, the inadequacy of environmental management units can be partially addressed by aligning with the SSB's Green Procurement Framework Plan. At a strategic level, the short-term profitability-focused production approach can be transformed into a vision that serves environmental sustainability through the adoption of long-term carbon neutrality targets. In this context, Table 3 comprehensively illustrates the challenges SMEs face in the green transformation and how these challenges can be transformed into strategic, financial, technological, and institutional opportunities.

3.4. Discussion of Findings

The findings show that the strategic orientation of the Turkish defense industry in its green transformation journey exists, but implementation deficiencies at the institutional capacity and supply chain level persist.

In international examples (e.g., Germany and Norway), integrating green transformation policies into defense procurement has led to both energy efficiency and operational cost reductions (EDA, 2021). In Türkiye, accelerating this transformation is possible through expanding technical support, financing, and training programs for SMEs.

Ultimately, the green transformation process is not only an environmental issue but also a strategic defense capability issue. The effective inclusion of Türkiye's defense industry SMEs in this process is critical to national defense sustainability.

3.5. Technological Applications and Innovation Areas

The success of the green transformation in the defense industry is largely linked to technological innovation capacity. Environmental sustainability in defense technologies today directly impacts not only the efficiency of production processes but also operational readiness, supply security, and strategic autonomy (OECD, 2023).

Significant progress has been made in Türkiye, particularly in the areas of energy efficiency, renewable energy integration, recycling systems, and carbon footprint monitoring technologies (TÜBİTAK, 2022). For example:

- ASELSAN facilities as of 2023, 10 million kWh of electricity will be produced annually and carbon emissions will be reduced by approximately 4,500 tons per year (ASELSAN, 2023).
- ROKETSAN recycles 60% of the waste generated during the production process and approaches EU standards in hazardous waste management (ROKETSAN, 2022).
- TAI is conducting trials to transition to " bio-based resin" systems in composite materials used in aircraft fuselage production (TAI, 2023).

These practices show that the transition to an environmentally friendly production model in the defense industry is no longer just a conceptual transformation, but a concrete technical one.

In addition, life cycle analysis (Life Cycle The LCA method is becoming increasingly widespread as a tool for minimizing the environmental impact of new defense platforms from the outset during the design phase (ISO, 2020). With the LCA approach, each of the material selection, production, usage, and recycling stages is evaluated on an energy and emissions basis.

Also digital twin (digital twin) and artificial intelligence-supported production simulations are used to optimize energy consumption in production lines, reduce waste, and calculate carbon footprints (Deloitte, 2023). The proliferation of these technologies offers significant gains not only in terms of environmental but also operational efficiency and maintenance planning (PwC, 2022).

Table 4. Green Technology Applications and Their Effects in the Defense Industry

Technology Area	Application Example	Environmental Impact	Operational Gain
Solar Energy Integration	10 MW solar power plant at ASELSAN facilities	4,500 tons of CO_2 reduction	20% reduction in electricity costs
Waste Recycling	ROKETSAN production waste	60% recovery rate	Reduction in raw material dependency
LCA Analysis	TAI platform design	Life cycle emissions measurement	15% reduction in product development time
Digital Twin Technology	MKE production lines	18% reduction in energy consumption	Optimization in maintenance planning

(ASELSAN, 2023; ROKETSAN, 2022; TÜBİTAK, 2022; Deloitte, 2023).

Table 4, illustrates both the environmental and operational benefits of green technology applications in the defense industry. Solar energy integration has reduced CO_2 emissions by 4,500 tons annually at a 10 MW power plant at ASELSAN facilities, while contributing to a 20% decrease in electricity costs. Waste recycling practices have reduced raw material dependency in ROKETSAN's production processes and increased the recovery rate to 60%. Thanks to the life cycle analysis (LCA) implemented by TAI in its platform design, product development time has been shortened by 15%, while MKE's use of digital twin technology has reduced energy consumption by 18%, enabling optimization in maintenance planning. These examples demonstrate that green technologies in the defense industry produce tangible results that reduce environmental impacts while simultaneously increasing operational efficiency (ASELSAN, 2023; Deloitte, 2023; ROKETSAN, 2022; TÜBİTAK, 2022).

Figure 2. Intersection of Digital and Green Technologies in the Defense Industry (SSB, 2022; Türkiye Defense Industry Strategy Document, 2022.)

Figure 2., illustrates the synergy between digital transformation (automation, artificial intelligence, digital twin) and green transformation (renewable energy, circular economy, sustainable materials). The integration of these two areas forms the basis for future " carbon-neutral defense production systems." The intersection of digital and green technologies in the defense industry offers a new paradigm that increases both the environmental and operational efficiency of production processes. The integration of digital twin, artificial intelligence, and IoT -based systems with renewable energy, carbon management, and waste reduction has given rise to the concept of " sustainable digitalization " in the defense industry (SSB, 2023; TÜBİTAK, 2022; OECD, 2023).

3.6. Institutional and Political Approaches

The institutionalization of green transformation in the defense sector is achieved through political will and strategic frameworks implemented in harmony with international norms.

NATO published its 2021 report “Climate Change and Security Action Plan” document, emphasized that climate change increases security risks and recommended that member states integrate environmental factors into operational planning in their defense systems (NATO, 2021). In this context, only 8 of the member states (including Türkiye) have officially integrated environmental management systems into their defense infrastructure (EDA, 2022).

Environmentally friendly defense management systems in line with NATO standards (SSB, 2023). The Presidency of Defense Industries' (SSB) 2022–2030 strategic plan aims for a systematic transformation in the sector through programs such as the " Green Procurement Framework " and the " Energy-Efficient Production Roadmap."

At the policy level, Türkiye's National Energy Efficiency Strategy (2022–2030), Zero Waste Regulation (2022), and Green Deal Action Plan (2021) have had indirect impacts on the defense sector (Ministry of Environment, Urbanization and Climate Change, 2022). With the integration of these policies into the sector, energy monitoring systems, environmental reporting mechanisms, and eco-efficiency indicators have been developed in production processes (Atlgan et al., 2025).

Policy coordination needs to be strengthened to ensure full alignment with international carbon reduction targets. Public-private partnerships, in particular, are expected to play an active role in standardizing green supply chains (World Bank, 2022).

Table 5. Comparison of Green Defense Policies in Türkiye and NATO Countries

Policy Area	NATO Countries (Average)	Türkiye	Development Level
Carbon Emission Reduction Target	50% (2035)	35% (2035)	Middle
Renewable Energy Use	40%	28%	Developing
Waste Management	70% recycling	55%	Developing
Green Procurement Policy	Compulsory	Voluntarily	Front end

(NATO, 2022; SSB, 2023; EDA, 2022; World Bank, 2022).

Table 5, compares the key elements of green defense policies implemented in Türkiye and selected NATO countries. The table covers key indicators such as environmental sustainability goals, renewable energy use in the defense industry, carbon emission reduction strategies, environmentally friendly supply chain practices, and green technology investments. The comparison reveals that many NATO member countries have integrated environmental criteria into their corporate policies in the defense field, while Türkiye has taken significant steps in this area and has potential for improvement in implementation. This table allows us to assess the progress of the green transformation in the defense sector by comparing Türkiye's current policies with international standards.

3.7. Strategic Importance of Green Transformation and National Security Dimension

The green transformation of the defense industry is not only an environmental necessity but also a strategic security measure. The role of green technologies is increasingly critical in reducing energy dependency, increasing the resilience of defense logistics chains, and ensuring wartime energy supply security (RAND, 2020).

Infrastructures based on renewable energy systems—for example, outposts powered by solar panels or base systems powered by hydrogen fuel cells —provide energy autonomy for military operations, reducing external dependency (NATO, 2022). In countries such as the US, Norway, and Germany, the carbon neutralization of such facilities has both reduced logistics costs and increased battlefield sustainability (RAND, 2023).

Given Türkiye's geopolitical position, the development of environmentally friendly defense technologies provides a strategic advantage both nationally and regionally. In this context, the green transformation process has become not only an "energy policy" but also a component of national security strategy (Karataş, 2023; Özdemir, 2024).

This new approach lies at the heart of the concept of " sustainable security." Sustainable security envisions the construction of defense systems not only in wartime but also in peacetime, on environmentally sensitive, energy-efficient, and economically resilient structures. Türkiye's steps in the defense industry represent the beginning of this conceptual transformation.

CONCLUSION, EVALUATION AND RECOMMENDATIONS

Green transformation in the defense industry has become a strategic imperative not only in terms of environmental sustainability but also in terms of economic resilience, national security and technological autonomy.

The findings indicate that Türkiye has made significant strides in this area over the past five years, but the structural transformation in SME-scale supply chains has not yet reached the desired level. While corporate awareness is increasing, particularly regarding carbon emission measurement, energy efficiency reporting, and sustainable supply management, standard practices need to be expanded.

Actors such as NATO, the European Defense Agency (EDA) and the US Department of Defense (DoD) have While integrating environmental objectives into military strategies through "Defense " programs, Türkiye's " Sustainable Production and Supply Program, " similarly led by the Presidency of Defense Industries (SSB), provides a crucial infrastructure (SSB, 2023). Furthermore, increasing financial, technical, and regulatory support to facilitate the active participation of SMEs in this ecosystem is critical.

The analysis of the study highlights the following policy recommendations for accelerating and institutionalizing the green transformation process:

Strengthening Institutional Strategy and Coordination

To ensure sustainability goals in the defense industry are permanent, a " **Green Defense Strategy Document " should be prepared under the coordination of the Presidency of Defense Industries (SSB).** This document should provide a binding framework for both public and private sector institutions on energy efficiency, carbon reduction, and environmental compliance (SSB, 2023; NATO, 2022).

Establishing Green Financing Mechanisms

Green loans, sustainability bonds, and carbon reduction incentives should be developed to support the transformation process of SMEs. A dedicated " Green Investment Fund" for the defense sector could be established in collaboration with international financial institutions (EBRD, World Bank, UNIDO) (World Bank, 2022; EBRD, 2022).

Technological Innovation and R&D-Focused Transformation

Low-carbon material technologies, waste recycling systems, and renewable energy-based military systems should be supported in collaboration with TÜBİTAK and universities (TÜBİTAK, 2022; Deloitte, 2023). In particular, digital twins, AI-assisted energy optimization, and life cycle analysis (LCA)-based systems can increase environmental efficiency in defense production.

Training and Capacity Building

Vocational training programs should be organized for defense industry employees on environmental awareness, energy efficiency, and sustainable production. Structures such as the " Green Defense Academy " should be established within the framework of university-industry collaborations to develop qualified human resources (Yıldırım & Şimşek, 2021).

International Cooperation and Standardization

Türkiye's EU Green Deal, NATO Green It is necessary to carry out a standardization process fully compatible with the Defense Program and the United Nations Sustainable Development Goals (UN-SDGs) (UNDP, 2021; EDA, 2021). In this context, it is recommended to disseminate environmental management systems such as ISO 14001, ISO 50001, and ISO 26000 across the defense industry production chain (ISO, 2020).

Carbon Reporting and Transparency Mechanisms

Companies must regularly report carbon emissions, energy consumption, and waste management data. **The National Defence Carbon Platform,** to be established under the leadership of the SSB, will be a critical tool for monitoring, benchmarking, and reporting sectoral emissions (OECD, 2023; PwC, 2022).

Dissemination of the Circular Economy Approach

The production, maintenance, and recycling processes of defense equipment should be based on circular economy principles (reduce – reuse – recycle) (OECD, 2021). This approach reduces waste, particularly in metal, composite, and electronic components, while also providing cost efficiency (World Bank, 2022).

Green Criteria in Public Procurement

environmental criteria (energy efficiency, carbon density, recyclability) mandatory in public procurement will be effective in transforming market dynamics. Commission, 2020). The establishment of the " Green Defense Procurement Standard " is a decisive policy tool in this process.

General Evaluation

The Turkish defense industry is progressing along three main axes of green transformation:

a. Energy Efficiency and Renewable Energy Use,
b. Waste Management and Circular Production,
c. Digitalization and Carbon Management Systems.

digital twins Technologies such as twin) need to be disseminated and supply chains need to be brought into compliance with ISO 14001 and ISO 50001 standards. In particular, the lack of support for subcontractor SMEs in this transformation process makes it difficult to ensure environmental integrity throughout the defense industry (OECD, 2023).

Future Assessment

The defense industry is a strategic sector that will shape the environmental and technological transformation of the future. Therefore, the success of the green transformation should be measured not only by environmental performance but also by indicators of technological independence, strategic resilience, and economic sustainability (Karataş, 2023; RAND, 2020).

Türkiye has the potential to become a regional innovation hub in green defense technologies within the next decade. Realizing this potential depends on establishing a strong culture of collaboration within the public-private-academic triangle and establishing a new strategic paradigm around environment and security (OECD, 2023; NATO, 2022).

Policy and Sectoral Recommendations

Recommendations for Defense Industry Policies:

a. Green tender" criteria should be introduced in defense procurement processes, and environmental performance indicators (carbon footprint, energy efficiency, waste rate) should be effective in tender scoring.
b. Mandatory environmental reporting and compliance with the ISO 14064 carbon management standard must be ensured for all contractors in the defense industry.
c. The cyclical design approach (design-use-recycling cycle) should be supported in defense technologies.

Table 6. Main Policy Areas of Green Transformation in the Defense Industry

Policy Area	Aim	Responsible Institution
Energy Efficiency	30% energy savings (2030)	SSB, Ministry of Energy
Carbon Reduction	2053 Net Zero target	Ministry of Environment, TUBITAK
Circular Production	Material recovery 50%	SSB, Defense Industry Clusters
Green Financing	1 billion TL green investment fund	Ministry of Treasury and Finance

(Source: Created by the author.)

Table 6, comprehensively summarizes the key policy areas driving the green transformation process in the defense industry. These policy areas include energy efficiency, sustainable production, waste management, carbon emission reduction, environmentally friendly supply chain practices, and green R&D activities. Each policy area aims to both reduce environmental impacts and maintain the sector's long-term competitiveness.

In this context, green transformation strategies offer a transformation perspective that not only supports environmental sustainability but also increases the innovation capacity of the defense industry, optimizes resource use and strengthens compliance with international standards.

Recommendations for SMEs:

a. should be financially incentivized with **Green Technology Transformation Funds** supported by TSKGV (Turkish Armed Forces Foundation) and TÜBİTAK.

b. **Green Transformation Training Programs "** for SMEs should be prepared and disseminated through digital platforms.

c. **Energy** audits in SMEs' production facilities **Audit)** should be streamlined and the results should be collected in a sectoral database.

Recommendations for Academy-Industry Collaboration:

a. Universities and research centers should conduct applied R&D projects in areas such as the use of low-carbon materials in military systems, nano-composites, and bio -based fuels.

b. **A "Green Defense R&D Platform" should be established** under the coordination of the Presidency of Defense Industries.

c. Joint projects on green defense themes should be developed from NATO and EU research funds.

Table 7. Applications of ISO 50001 and ISO 14064 in the Turkish Defense Industry (SSB, 2023)

Institution / Company	ISO 50001 (Energy Management)	ISO 14064 (Carbon Management)	Renewable Energy Rate
ASELSAN	Implemented (2021)	In the reporting phase	18%
ROKETSAN	Implemented (2022)	Implemented	22%
TAI	In the planning phase	Pilot application	12%
HAVELSAN	Implemented (2023)	Implemented	20%

(Presidency of Defense Industries [SSB], 2023)

Table 7, shows the implementation of international standards for energy management and greenhouse gas emissions in the Turkish defense industry. The ISO 50001 standard covers a systematic approach to increasing energy efficiency and reducing operational costs, while the ISO 14064 standard focuses on measuring, reporting, and reducing carbon footprints. The table provides a comparative overview of defense industry companies' adoption rates, areas of application, and levels of integration with these standards.

The results reveal that some prime contractors have strategically adopted ISO 50001 and ISO 14064 standards, while supplier SMEs have made partial progress in implementation. This table provides an important reference for analyzing the current state of environmental sustainability practices in the defense industry and identifying areas for improvement.

Sustainable Security and Future Perspective

The green transformation is transforming the classical understanding of security and bringing to the forefront new strategic concepts such as " energy security," " ecological resilience," and " technological autonomy." Accelerating the green transformation of Türkiye's defense industry is not only an environmental goal but also a necessary step for the sustainability of national security.

In this context, Türkiye's long-term military and economic independence will not be fully achieved unless the green production capabilities of defense industry SMEs are developed. Therefore, a green defense approach will directly determine Türkiye's competitiveness and strategic maneuverability in the hybrid threat environments of the future (Karataş, 2023; RAND, 2024; OECD, 2023).

As a result, the green transformation in Türkiye's defense industry ecosystem is no longer just an environmental policy; it has become the new determinant of economic sustainability, competitiveness, and security. Increasing the participation of SMEs in this transformation, accelerating the transition to green production technologies, and strengthening compliance with international standards will be crucial for Türkiye to achieve its 2030 and 2053 goals.

Suggestions for Future Research

This study evaluated the current state of green transformation policies in the Turkish defense industry by comparing them with international examples. However, to more thoroughly analyze the long-term impact of this transformation, it is recommended that future research focus on the following areas:

1. **Quantitative Impact Analyses and Performance Measures**

   Multivariate econometric models, carbon cost simulations, and energy efficiency indices should be used to measure the economic, environmental, and operational impacts of green technologies in the defense industry. Such empirical analyses can provide more concrete insights into policy outcomes.

2. **Microdata-Based Studies at the SME Level**

   Future research should be conducted using micro-scale data collection methods (surveys, in-depth interviews, case studies) on the transformation processes of supplier SMEs to better understand specific barriers to transformation and regional differences.

3. **Defense Industry–Climate Security Interaction**

   The impacts of climate change on defense strategies (e.g., military logistics, energy security, disaster support operations) should be examined with quantitative models. In this context, the concept of " **green defense** " can be redefined in an integrated way with the classical security paradigm.

4. **Network Analysis of the Green R &D Ecosystem**

   Green innovation networks among universities, research institutions, and defense industry companies should be examined using social network analysis (SNA). Such a study can reveal the ecosystem's weak and strong ties by measuring knowledge flow and collaboration density.

5. **Comparative Policy Studies Policy Studies)**

Comparing Türkiye's green defense policies with defense-industry-environment integration models in countries such as the United States, South Korea, and Japan can offer valuable insights for new policy formulations.

6. **Impact Analysis of Artificial Intelligence and Digital Twin Applications**
   Digital twin technology has revolutionary potential for energy and maintenance optimization. Future research could model the quantitative impact of these technologies on carbon reduction in defense production.
7. **The Relationship Between Green Finance and Defense Economics**
   The applicability of green bonds, sustainability loans, and carbon markets in the defense sector should be analyzed from a financial sustainability perspective. Public-private financing models can be examined in detail in this area.
8. **Social Acceptance and Institutional Culture Analysis**
   The impact of environmental awareness on employee motivation and organizational commitment in defense institutions could be investigated. This would make the social dimension of green transformation more visible.

REFERENCES

ASELSAN. (2023). Sustainability Report 2023. Ankara.

Atılgan, SS., Tanyaş, M., Öz, S., (2025), Use of Electric Vehicles in Sustainable Urban Logistics, Journal of İstanbul School of Technology (JISTECH), 1(1), pp 1-22.

Bitzinger, R. (2020). Defense innovation and environmental sustainability RAND Corporation.

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. Qualitative Research in Sport, Exercise and Health, 11(4), 589–597.

Brundtland, GH (1987). Our common future : Report of the World Commission on Environment and Development. Oxford University Press.

Brzoska, M. (2019). The military and climate change : Security implications. SIPRI Policy Paper.

Ministry of Environment, Urbanization and Climate Change. (2022). Zero Waste Regulation. Ankara.

Creswell, J.W. (2018). Research design : Qualitative, quantitative, and mixed methods approaches. Sage.

Deloitte. (2023). Sustainability and digital twin integration in defence. London.

SPO. (2020). Eleventh Development Plan (2019–2023). Presidency of the Republic of Türkiye, Strategy and Budget Directorate, Ankara.

DoD. (2021). Sustainable Defense Logistics Strategy. US Department of Defense.

EDA. (2020). Green Defense Framework. European Defense Agency, Brussels.

EDA. (2022). Environmental Sustainability in Defense Supply Chains. European Defense Agency.

EDA. (2021). Sustainability in Defense Supply Chains. European Defense Agency, Brussels.

EDA. (2022). European Green Defense Strategy. European Defense Agency, Brussels.

EBRD. (2022). Green transition in emerging defense industries. London.

European Commission. (2020). The European Green Deal. Brussels.

EU. (2020). European Industrial Strategy for a Green Transition. Brussels.

IEA. (2023). Energy efficiency and defense industries Paris: International Energy Agency.

ISO. (2020). Environmental management systems – ISO 14001 guidelines. Geneva.

ISO. (2022). Carbon footprint standards – ISO 14064. Geneva.

ISO. (2023). Environmental management systems – ISO 14001 implementation guide. Geneva.

Karataş, H. (2023). Environmental sustainability and energy security in the defense industry. Gazi University Publications.

MKE. (2023). Corporate Sustainability Report. Ankara.

NATO. (2014). Smart Energy and Green Defense Initiative. Brussels.

NATO. (2020). Green Defense Framework Implementation Report. Brussels.

NATO. (2021). Climate Change and Security Action Plan. Brussels.

NATO. (2022). Green Defense Framework. Brussels.

NATO. (2023). Climate Change and Security Action Plan. Brussels.

OECD. (2020). Greening defense industry : Policy insights. Paris.

OECD. (2021). Circular economy in the defense sector. Paris.

OECD. (2023). Green industry policy outlook 2023. Paris.

OECD. (2023). Green Transition and Defense Industry Adaptation Report.

Önder Savunma. (2023). Defense technologies for a sustainable future. https://www.ondersavunma.com/surdurulebilir-bir-gelecek-icin-savunma-teknolojileri (Access Date: 10.10.2025)

Öz, S., (2022). İstanbul School of Metaverse: Bir Meta İş Planı Çalışması, Chapter in book: Metaverse, İstanbul, Hiperyayın, 221-296.

Öz, S., (2025). A Bibliometric Analysis on Bokashi Technique which is used for Implementing Circular Economy in Food Waste, Journal of İstanbul School of Technology (JISTECH), 1(1), pp 98-118.

Özdemir, S. (2024). The impact of green transformation on defense strategies. International Journal of Security Studies, 12(2).

Patton, M. Q. (2015). qualitative research & evaluation methods. Sage.

PwC. (2022). Energy efficiency in defense manufacturing. London.

RAND Corporation. (2020). Climate change and national security. Washington, DC

RAND Corporation. (2024). Green Defense and Climate Resilience Strategies.

ROKETSAN. (2022). Sustainability Report 2022. Ankara.

SSB. (2022). Defense Industry 2022 Sustainability Report. Ankara.

STM Business Ecosystem. https://www.stm.com.tr/tr/stm-is-ekosistemi (Access Date: 10.10.2025)

Republic of Türkiye Ministry of Trade. (2021). Green Deal Action Plan. Ankara.

TUBITAK. (2021). Carbon reduction technologies in industry report. Ankara.

TUBITAK. (2022). Carbon reduction technologies in the defense industry report. Ankara.

TÜBİTAK. (2022). Green Technology and Defense R& D Strategy Report.

TÜSİAD. (2021). Industry 4.0 applications in green transformation. Istanbul.

UNDP. (2021). Sustainable development goals report. New York.

UNEP. (2022). Environmental security and green industry transition. Nairobi.

World Bank. (2022). Green transition policy toolkit. Washington, DC

World Bank. (2022). Financing Sustainable Defense Industries.

Yıldırım, A., & Şimşek, H. (2021). Qualitative research methods in social sciences. Seçkin Publishing.