



The Potential of the Triple Helix Model in Developing Directed Energy Weapons (DEWs) for National Defense Industry Independence

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Abstrak

The evolution of the strategic environment shaped by the Fourth Industrial Revolution has driven the integration of emerging technologies into advanced weapon systems, including Directed Energy Weapons (DEWs). DEWs utilize focused energy forms such as lasers, microwaves, and particle beams to neutralize targets with high precision and speed. This paper explores the role of the Triple Helix Model collaboration among government, academia, and industry in advancing national defense technology, particularly DEWs, toward achieving defense industrial independence. Through literature review and policy analysis, it argues that a well-implemented Triple Helix framework can strengthen civil-military cooperation, enhance innovation capacity, and foster sustainable development of DEW technology within Indonesia's defense ecosystem.

Keywords: Directed Energy Weapons, Triple Helix Model, Defense Industry, Civil-Military Cooperation, Innovation.

INTRODUCTION

The global defense landscape has entered a new phase characterized by rapid technological convergence, where traditional kinetic warfare is increasingly supplemented by information, cyber, and electromagnetic dimensions. The Fourth Industrial Revolution, also known as Industry 4.0, has introduced disruptive technologies such as artificial intelligence, robotics, nanotechnology, and quantum computing, all of which have significant implications for the modernization of military capabilities. Among these emerging technologies, Directed Energy Weapons (DEWs) stand out as one of the most transformative innovations in the realm of modern warfare.

Directed Energy Weapons operate by focusing energy, whether in the form of lasers, microwaves, or particle beams, toward a target to disable, damage, or destroy it without relying on traditional kinetic projectiles. This fundamental difference from conventional weaponry allows DEWs to achieve unparalleled accuracy, speed, and flexibility on the battlefield. The energy is transmitted and accumulated at the target until it surpasses the threshold that causes material disruption or system failure. This mechanism grants DEWs the ability to neutralize threats at the speed of light, engage multiple targets rapidly, and minimize collateral damage, thus representing a major leap forward in modern defense strategy (Spencer, 2020; GAO, 2023).

The potential applications of DEWs extend beyond traditional combat. They are increasingly being used for air and missile defense, counter-drone operations, surveillance, and electronic warfare. The United States Department of Defense, for instance, has established the Directed Energy Futures 2060 program, envisioning DEWs as a cornerstone of multi-domain operations that integrate land, sea, air, space, and cyber capabilities (U.S. DoD, 2021). Similarly, other advanced defense actors including the United Kingdom, China, and Australia have invested in DEW research and development as part of their long-term strategic modernization plans (Pudo & Galuga, 2017; DoD Australia, 2023).



For Indonesia, the adoption and indigenization of advanced military technologies such as DEWs are crucial to achieving the goal of defense industrial independence as mandated by Law No. 3 of 2002 on National Defense and Law No. 16 of 2012 on the Defense Industry. These laws emphasize that national defense capabilities must be supported by a self-reliant defense industry capable of research, development, and production of strategic weapon systems. In this context, innovation is not merely a technological pursuit but a national imperative that ensures the sustainability and sovereignty of Indonesia's defense capabilities.

The Triple Helix Model, first conceptualized as a framework for innovation through the collaboration of three key sectors, government, academia, and industry, offers a robust structure for achieving technological advancement and self-reliance in defense production. In the defense sector, this model can be translated into a dynamic ecosystem where government policies provide direction and funding, academic institutions contribute research, innovation, and skilled human resources, and industries focus on technological application, manufacturing, and commercialization. The integration of these three pillars enables efficient knowledge transfer, enhances national technological competitiveness, and accelerates the transition from research to deployment.

Indonesia's Ministry of Defense has recognized the importance of such collaboration in the national defense innovation ecosystem. The formation of Defend ID, a state-owned defense industry holding that includes PT LEN Industri, PT Pindad, PT PAL, PT Dirgantara Indonesia, and PT Dahana, embodies the operationalization of the Triple Helix Model within the Indonesian context. Each entity contributes unique technological capabilities that, when synergized with government and academic research institutions, can drive the development of indigenous DEW technologies. The Ministry's Regulation No. 12 of 2021 further emphasizes modernization through the integration of advanced systems such as Network-Centric Warfare, Cyber Defense, and Electromagnetic Spectrum Operations, all of which are technically aligned with DEW capabilities.

Furthermore, the global shift toward civil-military integration highlights that defense technology development cannot be isolated within the military domain alone. Collaboration with civilian research institutions and private industries allows the cross-pollination of ideas and technologies that enhance innovation. The Triple Helix Model thus aligns with the broader civil-military cooperation strategy, which emphasizes joint efforts to achieve technological superiority and operational interoperability between civilian and military sectors. This collaborative paradigm not only promotes defense self-reliance but also contributes to national economic growth by fostering high-technology industries with dual-use potential.

In summary, the emergence of Directed Energy Weapons as a disruptive military technology presents both a challenge and an opportunity for Indonesia. The challenge lies in overcoming technological dependence and capability gaps, while the opportunity resides in leveraging the Triple Helix Model to build a sustainable and self-reliant defense innovation ecosystem. By integrating government support, academic excellence, and industrial capacity within a coordinated policy framework, Indonesia can establish itself as a regional leader in advanced defense technologies and strengthen its strategic autonomy.

RESEARCH METHODS

This research adopts a qualitative descriptive approach using a literature review of government documents, scientific reports, and defense publications related to DEWs and the Triple Helix Model. Sources include official Ministry of Defense publications, reports by the U.S. Government Accountability Office (GAO, 2023), Department of Defense Science and Technology (Australia, 2023), and academic analyses such as those by the Faculty of Law, University of Oslo (2022). The method aims to synthesize policy relevance, technological feasibility, and institutional collaboration models to support national defense innovation.

RESULT AND DISCUSSION

Technological Development of Directed Energy Weapons (DEWs)

Directed Energy Weapons represent one of the most significant advancements in military technology over the past few decades. These systems function by delivering focused energy in the form of electromagnetic radiation, such as lasers, microwaves, or particle beams, directly to a target. Unlike conventional weapons that rely on the transfer of kinetic or explosive energy, DEWs use concentrated electromagnetic energy to produce a physical or electronic effect on the target. This unique operational mechanism allows for instantaneous engagement, precise targeting, and the potential for repeated use without the need for traditional ammunition (Spencer, 2020; Ellis, 2015).

There are two main categories of DEWs currently under development and deployment: High Energy Lasers (HEL) and High Power Microwaves (HPM). HEL systems utilize coherent light beams to damage or destroy physical components of a target, such as airframes, sensors, or optical instruments. These systems rely on adaptive optics, beam control, and cooling systems to maintain beam quality and effectiveness under various atmospheric conditions. On the other hand, HPM systems emit bursts of microwave energy designed to disrupt or destroy electronic components within a target area. HPM weapons can disable multiple electronic systems simultaneously, making them especially effective against drones, communications networks, and other electronically dependent assets (Pudo & Galuga, 2017; GAO, 2023).

HEL and HPM systems share common features such as energy projection, the need for substantial power sources, integration with command and control systems, and deployment on mobile or stationary platforms. However, their operational effects differ significantly. HEL focuses on physical destruction by heating and melting materials, while HPM operates primarily through electromagnetic interference, overloading circuits, and rendering electronic devices inoperable. The lethality of each system is determined by factors including power output, duration of exposure, atmospheric interference, and target material composition.

Internationally, the United States has made significant progress in DEW research and deployment through its High Energy Laser Joint Technology Office and the Robust Electric Laser Initiative (RELI). These initiatives have resulted in several successful prototypes, such as the Advanced Test High Energy Asset (ATHENA) system developed by Lockheed Martin, which has demonstrated the capability to neutralize multiple Unmanned Aerial Vehicles (UAVs) under field conditions (U.S. DoD, 2021; GAO, 2023). Similarly, the U.K.'s Dragonfire consortium, consisting of major defense firms like MBDA, BAE Systems, and QinetiQ, has advanced HEL development for naval applications, aiming to integrate these systems into Royal Navy platforms.

China's research in High Power Microwave technologies, conducted by the Northwest Institute of Nuclear Technology, has reportedly achieved breakthroughs in non-kinetic defense capabilities. These efforts align with China's broader strategic focus on electromagnetic dominance and informationized warfare. Russia, on the other hand, has operationalized its Peresvet laser systems within the Russian Armed Forces, demonstrating its growing emphasis on energy-based weaponry as part of its military modernization program (Faculty of Law, University of Oslo, 2022).

Australia's Department of Defence has also invested in Directed Energy research under its Emerging Disruptive Technology Assessment Symposium (EDTAS) program, identifying DEWs as critical to future military readiness and defense self-reliance (DoD Australia, 2023). These global advancements collectively signify a paradigm shift in military doctrine, where control over the electromagnetic spectrum becomes a decisive factor in achieving battlefield superiority.

For Indonesia, the exploration and eventual integration of DEWs represent both a technological and strategic necessity. As modern warfare increasingly relies on speed, precision, and information dominance, the ability to develop indigenous DEW capabilities will determine the extent of national defense autonomy. Integrating DEWs into Indonesia's defense modernization agenda will not only enhance its deterrence capability but also drive innovation within the domestic defense industry. However, achieving this goal

requires substantial investment in research and development, human resource capacity building, and institutional collaboration, which can be effectively facilitated through the Triple Helix Model.

In this context, the development of DEWs in Indonesia should not be viewed solely as a technological project but as a strategic national initiative. Through the combined efforts of government, academia, and industry, the nation can foster a sustainable innovation ecosystem that supports the entire lifecycle of DEW technology, from concept to deployment. The Triple Helix Model provides the structural framework for such collaboration, ensuring that DEW development aligns with both national defense objectives and broader technological progress.

Legal and Ethical Framework

The development and potential deployment of Directed Energy Weapons (DEWs) raise complex legal and ethical questions within the broader context of international humanitarian law (IHL) and the law of armed conflict. While technological innovation in defense is essential for maintaining national security and strategic deterrence, it must also comply with established international norms that regulate the use of force. The absence of specific and comprehensive legal provisions regarding DEWs presents a significant challenge to both policymakers and defense institutions.

At the international level, the existing framework primarily derives from the 1980 Convention on Certain Conventional Weapons (CCW), which aims to prohibit or restrict weapons that cause unnecessary suffering or have indiscriminate effects. In 1995, the United Nations adopted the Protocol on Blinding Laser Weapons (Protocol IV), which explicitly bans the use of laser weapons designed to cause permanent blindness. However, this protocol does not cover the broader spectrum of Directed Energy Weapons, such as High Power Microwaves (HPM) or High Energy Lasers (HEL) used for disabling equipment rather than targeting human beings (Faculty of Law, University of Oslo, 2022). This gap in regulation leaves much of DEW development and potential use in a legal grey area.

The ethical debate surrounding DEWs is rooted in concerns over their invisibility, potential for silent and non-lethal harm, and the possibility of misuse in civilian contexts. Unlike conventional weapons that leave physical evidence, DEWs can inflict damage or pain without visible traces, complicating accountability and post-incident verification. The Active Denial System (ADS), for example, which uses millimeter-wave radiation to produce an intense heating sensation on human skin, has raised serious human rights concerns despite being classified as non-lethal. Critics argue that such systems could be used for crowd control or coercive measures against civilians, challenging principles enshrined in international human rights law (Hatfield, 2016; Oakes & Smith, 2013).

Moreover, the potential dual-use nature of DEW technologies—where the same systems can be used for both military and civilian purposes—introduces further ethical complexities. While dual-use innovation can promote economic and technological growth, it also necessitates strict regulation and oversight to prevent proliferation and misuse. The absence of standardized international norms makes it difficult to establish accountability mechanisms or ensure compliance with proportionality and distinction principles under IHL.

For national policymakers, these concerns highlight the importance of developing a robust regulatory framework that governs the research, testing, and deployment of DEWs. Indonesia, as a signatory to multiple international disarmament and humanitarian conventions, must align its defense innovation strategy with international obligations while safeguarding national interests. Law No. 3 of 2002 on National Defense and Law No. 16 of 2012 on the Defense Industry already emphasize the need for ethical and responsible innovation, but additional measures are required to address emerging technologies such as DEWs.

Ethical governance of DEWs also requires transparency, oversight, and the inclusion of multidisciplinary perspectives. Collaboration among defense institutions, legal experts, and academic researchers can ensure that technological progress remains consistent with humanitarian principles. In this respect, the Triple Helix Model can serve not only as a mechanism for innovation but also as a framework for ethical stewardship. By incorporating legal scholars and policy analysts into the innovation process, the model ensures that advancements in DEW technology adhere to both national laws and international norms.

In conclusion, while DEWs offer transformative capabilities that can redefine modern warfare, their development must proceed within a clear legal and ethical framework. Establishing such a framework requires proactive national policy, engagement in international dialogue, and the institutionalization of ethical oversight mechanisms. Indonesia's path toward defense innovation through the Triple Helix Model should therefore integrate legal and moral accountability as fundamental components of technological advancement.

The Triple Helix Model and Defense Innovation

The Triple Helix Model represents a dynamic framework that integrates the roles of government, academia, and industry in fostering technological innovation and sustainable development. Within the context of defense innovation, this model emphasizes that no single sector can independently achieve technological breakthroughs without the support and collaboration of the others. The model's strength lies in its ability to create a synergy where each actor contributes its unique competencies: government provides regulatory and financial frameworks, academia generates knowledge and research, and industry transforms innovation into practical, marketable applications.

In the field of defense technology, the Triple Helix Model has become increasingly relevant due to the complexity and interdependence of modern weapon systems. Directed Energy Weapons (DEWs), as a prime example, require extensive research, cross-sectoral expertise, and technological integration. Developing DEWs involves advanced physics, materials science, energy systems, and computer modeling, all of which demand close cooperation among universities, research institutions, defense industries, and the government. Therefore, the Triple Helix Model serves not only as a theoretical innovation concept but also as a practical mechanism for national defense capability building.

In Indonesia, the implementation of the Triple Helix Model in the defense sector has been reflected in various institutional policies and strategic initiatives. The establishment of **Defend ID**, a state-owned defense industry holding that consolidates PT LEN Industri, PT Pindad, PT PAL, PT Dirgantara Indonesia, and PT Dahana, represents a structural manifestation of this model. Each company specializes in different strategic domains—land, sea, air, electronic systems, and munitions—collectively forming the industrial backbone for Indonesia's defense innovation ecosystem. The government, through the Ministry of Defense, acts as both the policymaker and facilitator, while higher education and research institutions serve as the main sources of scientific advancement and human capital development.

The synergy between these three pillars enables the creation of a defense ecosystem that promotes technology transfer, innovation diffusion, and local content enhancement. For instance, PT LEN Industri's focus on C6ISR (Command, Control, Communication, Computers, Cyber-Defense, Combat Systems, Intelligence, Surveillance, and Reconnaissance) platforms provides a foundation for integrating DEW systems into broader defense networks. Academic institutions such as the Indonesian Defense University (Unhan) and leading technical universities play crucial roles in supporting research and developing a skilled workforce capable of mastering DEW technologies. Meanwhile, the industrial sector provides prototyping, production, and maintenance capabilities that transform research outputs into operational systems.

From a policy perspective, the Ministry of Defense Regulation No. 12 of 2021 on National Defense Policy 2020–2024 explicitly highlights defense modernization through advanced technologies such as Network-Centric Warfare, Cyber Defense, and Electromagnetic Spectrum Operations. These strategic directions align directly with DEW development, where mastery of electromagnetic technologies serves as a key enabler for defense superiority. The regulation also emphasizes the need for cooperation with academic institutions and industries to strengthen research and innovation capacity. This clearly reflects the spirit of the Triple Helix Model, where institutional synergy drives the translation of knowledge into practical military solutions.

Beyond the structural and institutional framework, the Triple Helix Model also supports **dual-use innovation**, which bridges the gap between military and civilian technological applications. Many DEW-related technologies, such as high-energy lasers and microwave systems, have potential uses in telecommunications, aerospace, and energy industries. Through collaborative research and knowledge-sharing

mechanisms, these innovations can generate broader socio-economic benefits, reinforcing the link between national security and technological progress. This dual-use orientation not only strengthens national defense capabilities but also contributes to industrial competitiveness and economic growth.

However, the successful implementation of the Triple Helix Model in defense innovation also faces several challenges. Bureaucratic barriers, limited research funding, and the lack of effective intermediary institutions often hinder the optimal exchange of knowledge among stakeholders. In addition, gaps between academic research and industrial production remain a major obstacle to commercialization and deployment. To overcome these issues, Indonesia must enhance coordination mechanisms, develop long-term defense research funding schemes, and establish innovation intermediaries—such as defense technology clusters or centers of excellence—to bridge institutional and disciplinary divides.

In summary, the Triple Helix Model provides a comprehensive framework for accelerating defense innovation, particularly in the development of Directed Energy Weapons. By fostering strategic collaboration between the government, academia, and industry, Indonesia can strengthen its research and development ecosystem, reduce dependence on foreign technologies, and promote the creation of indigenous defense systems. The model not only facilitates technological advancement but also reinforces the foundation of civil-military cooperation, ensuring that defense innovation contributes to both national security and sustainable industrial growth.

Strengthening Civil-Military Cooperation (CMC)

Civil-Military Cooperation (CMC) plays an increasingly significant role in the advancement of national defense capabilities, particularly in the context of modern, technology-driven security environments. CMC embodies the collaboration between military institutions and civilian sectors to optimize resource utilization, enhance innovation, and achieve strategic objectives that contribute to national resilience. Within the framework of the Triple Helix Model, CMC serves as an operational mechanism that facilitates interaction between government, academia, and industry to accelerate technological development and defense modernization.

In Indonesia's defense context, the strengthening of CMC is crucial to realizing technological self-reliance and industrial independence. The integration of Directed Energy Weapons (DEWs) into national defense strategies requires multi-sectoral cooperation that bridges military requirements with civilian technological expertise. The government acts as the central coordinator, formulating policies, allocating budgets, and establishing regulatory mechanisms to support innovation. Meanwhile, academic institutions contribute through advanced research, scientific exploration, and the development of specialized human resources, while industries implement and commercialize these innovations into practical applications. This triadic cooperation ensures that innovation processes are efficient, adaptive, and aligned with national strategic priorities.

The modernization of Indonesia's defense system, as stipulated in the Ministry of Defense Regulation No. 12 of 2021, emphasizes the importance of technological integration in domains such as Network-Centric Warfare, Cyber Defense, and Electromagnetic Spectrum Operations. These areas directly intersect with DEW technologies, which rely heavily on the control and exploitation of the electromagnetic spectrum. The synergy between civil and military entities within this framework enhances interoperability and facilitates the integration of DEWs into broader defense architectures. It also creates a foundation for long-term collaboration where research institutions, universities, and industries can align their objectives with the operational needs of the Indonesian Armed Forces (TNI).

From a broader perspective, CMC also supports the dual-use concept of technology, which encourages the application of defense research for civilian benefits and vice versa. Directed Energy technologies, for instance, have potential uses in space exploration, telecommunications, and industrial manufacturing. Through the Triple Helix approach, the cross-sectoral flow of knowledge and technology enhances not only military readiness but also national economic competitiveness. This reciprocal relationship between defense

and civilian sectors exemplifies how CMC can drive innovation ecosystems beyond traditional military boundaries.

Internationally, CMC has proven to be a vital factor in successful defense innovation strategies. The United States, for example, maintains extensive partnerships between the Department of Defense, universities, and private industries, forming an innovation ecosystem that continually generates breakthroughs in defense technologies, including DEWs (U.S. DoD, 2021). Similarly, Australia's Emerging Disruptive Technology Assessment Symposium (EDTAS) involves academic experts and industry leaders in identifying technologies critical to future defense capabilities (DoD Australia, 2023). These models demonstrate that sustained collaboration and information exchange between civil and military sectors are fundamental to achieving technological superiority and maintaining strategic autonomy.

For Indonesia, strengthening CMC within the Triple Helix framework requires several strategic actions. First, institutional mechanisms for collaboration must be formalized, ensuring that defense research programs include representatives from academic and industrial communities. Second, funding structures should encourage joint research initiatives and technology transfer agreements that prioritize local innovation. Third, human capital development must focus on fostering scientists, engineers, and defense professionals capable of bridging the gap between research and practical implementation. Establishing centers of excellence dedicated to Directed Energy research and defense technology innovation would further institutionalize CMC and Triple Helix cooperation.

Moreover, the implementation of CMC contributes to transparency and accountability in defense innovation. By involving civilian institutions in research and oversight, the government ensures that technological advancements align with ethical standards and public interest. This collaborative environment not only enhances national security but also builds public trust in defense institutions, promoting a culture of collective responsibility for technological progress and national resilience.

In conclusion, Civil-Military Cooperation under the Triple Helix Model serves as a cornerstone for Indonesia's defense innovation and industrial independence. By fostering collaboration between government agencies, academic institutions, and private industries, Indonesia can establish a self-reliant and adaptive defense ecosystem capable of mastering advanced technologies such as Directed Energy Weapons. The integration of CMC ensures that innovation is inclusive, ethically grounded, and strategically directed toward strengthening both national defense and broader societal development.

CONCLUSION

The development of Directed Energy Weapons (DEWs) is essential for Indonesia's goal of achieving defense industry independence. As warfare evolves toward precision and speed through electromagnetic technologies, DEWs offer strategic advantages in strengthening national security. However, developing these technologies requires cooperation among multiple sectors. The Triple Helix Model provides a strong foundation for integrating government policy, academic research, and industrial innovation. Through this model, the government can guide policy and funding, universities can contribute research and expertise, and industries can translate technology into defense applications. This synergy ensures that innovation remains aligned with national priorities. Civil-Military Cooperation (CMC) supports this framework by linking military needs with civilian capabilities. The collaboration promotes dual-use technology development, boosts research efficiency, and fosters sustainable industrial growth. Yet, challenges such as limited research funding and coordination gaps must be addressed to realize its full potential. In summary, applying the Triple Helix Model in the development of DEWs will enhance Indonesia's defense innovation ecosystem, reduce technological dependence, and strengthen strategic autonomy. Collaboration, ethical regulation, and continuous research investment are key to transforming this vision into a sustainable national capability.

REFERENCES

- Article 36 United Kingdom. (2017). *Directed Energy Weapons*. Discussion Paper for the Convention on Certain Conventional Weapons (CCW). Geneva.
- Department of Defence Science and Technology Australia. (2023). *Emerging Disruptive Technology (EDTAS) Assessment Symposium: Directed Energy Technology Insights Paper*. Noetic Group.
- Ellis, J. D. (2015). *Directed-Energy Weapons: Promise and Prospects*. Center for a New American Security.
- Faculty of Law, University of Oslo. (2022). *Laser and Directed Energy Weapons within International Humanitarian Law*.
- Gunzinger, M., & Dougherty, C. (2012). *Changing the Game: The Promise of Directed-Energy Weapons*. Center for Strategic and Budgetary Assessments (CSBA).
- Hatfield, M. (2016). *Active Denial Technology*. Naval Surface Warfare Center, U.S. Department of Defense.
- Pudo, D., & Galuga, J. (2017). *High Energy Laser Weapon Systems: Evolution, Analysis, and Perspectives*. Defence Research and Development Canada.
- Report to Congressional Committees. (2023). *Directed Energy Weapons: DoD Should Focus on Transition Planning*. U.S. Government Accountability Office (GAO).
- Spencer, M. (2020). *Directed Energy Weapons: Playing with Quantum Fire*. Air Power Development Centre, Department of Defence Australia.
- U.S. Department of Defense. (2021). *Directed Energy Futures 2060: Visions for the Next 40 Years of U.S. Directed Energy Technologies*.
- Republic of Indonesia. (2002). *Law No. 3/2002 on National Defense*.
- Republic of Indonesia. (2012). *Law No. 16/2012 on the Defense Industry*.
- Republic of Indonesia. (2021). *Ministry of Defense Regulation No. 12/2021 on National Defense Policy 2020–2024*.
- Ministry of Defense of Indonesia. (2023). *Round Table Discussion on Triple Helix for Defense Innovation*. Directorate General of Defense Potential (Kemhan).