Product Lifecycle Management in the Field of Green Energy: Product Management Approaches

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Abstract: The article examines the approaches of product management in the process of product lifecycle management in the field of green energy. This, in turn, is due to the growth of the global green energy market, accompanied by stricter environmental requirements, actualized by the need to apply product lifecycle management (PLM) as a strategic tool in the product policy of companies. The main purpose of this study is to identify key product management techniques and approaches aimed at increasing sustainability and environmental responsibility at all stages of the product life cycle, including planning, design, production, operation and disposal.

The study analyzes the best practices of market leaders such as Ørsted, Siemens Gamesa and Tesla, who actively use PLM to integrate digital solutions and the principles of a circular economy. The methodology is based on the study of data on the use of digital twin technologies, process automation and eco-design, which reduces the carbon footprint of products, minimizes production costs and increases resource efficiency.

The results show that PLM not only supports innovative development, but also contributes to the creation of business models that comply with the principles of sustainable development. Thus, effective product lifecycle management allows companies in the green energy sector to achieve competitive advantages by implementing environmentally friendly technologies and ensuring adaptation to current and future challenges of the global market.

Keywords: product lifecycle management, green energy, product management, sustainable development, digitalization, circular economy, ecodesign.

Introduction

The modern energy sector faces the necessity of a global shift toward renewable energy sources due to both the growing scarcity of natural resources and the demands of environmental sustainability. The green energy industry is developing at a rapid pace, driving demand for innovative technologies and eco-friendly solutions that can minimize negative environmental impact. Under these conditions, Product Lifecycle Management (PLM) has become an essential component for companies operating in the green energy sector. PLM enables the organization of all stages of product creation and operation in a way that achieves high environmental efficiency, reduces the carbon footprint, and enhances market competitiveness.

The relevance of this topic is driven by increasing demands for corporate environmental responsibility and the growing influence of environmental standards and government programs. Leading companies in the industry, including corporations like Ørsted and Siemens Gamesa, are successfully implementing PLM to optimize the processes of product design, production, operation, and disposal. This approach minimizes the use of natural resources and increases material recyclability, creating a closed production loop and reducing the ecological burden. Moreover, the digitalization of processes and the introduction of technologies such as digital twins and automated control systems contribute to sustainable development by optimizing resource use and reducing operating costs.

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The purpose of this work is to analyze key product lifecycle management methodologies in the green energy sector and to examine their impact on the sustainable development of companies.

Materials and Methods

The methods used in this article include comparative analysis, systematization, generalization, and the examination of practical examples demonstrating product management approaches within product lifecycle management (PLM) in the green energy sector.

According to a study on the global clean energy market published on linkedin.com [1], the market volume reached $644.19 billion in 2023. This source highlights the increasingly innovative role of "green" technologies in various countries' energy systems, driven by the need to reduce energy consumption and enable continuous energy use. The article "Product Green Design and Management" [2] on liteon.com discusses sustainable environmental approaches to design and production management, which help reduce the environmental impact at each stage of a product's lifecycle, from design to disposal. This work notes that environmental product management has become a part of corporate responsibility aimed at waste minimization.

Ahmad T. et al. [3] observe that artificial intelligence is playing an increasingly significant role in the sustainable energy industry, offering innovative solutions for process optimization and resource efficiency. Husin H. et al. [4] argue that integrating renewable energy sources with various technologies remains a complex task requiring critical analysis and the development of new approaches.

Gawusu S. et al. [5] indicate that sustainable practices in green supply chain management within renewable energy can significantly enhance enterprise efficiency and competitiveness. The article "Urban Green Spaces: Combining Goals for Sustainability and Placemaking" [6], published on europenowjournal.org, describes the innovative impact of green urban spaces, which continually address developmental challenges and improve urban environmental quality. This work emphasizes that these spaces contribute to the environmental health of cities while enhancing residents' mental well-being and supporting urban labor development.

The practical aspect of this issue was examined through the example of renewable energy innovations by Siemens Gamesa [7]. The impact of digital twin technology on the energy industry was explored in the source medium.com [8] in an article titled "The Impact of Digital Twins on the Energy Industry." Additionally, solar panel recycling methods were investigated in [9], published on greentechrenewables.com, which highlights the importance of effective recycling methods to minimize the environmental impact of decommissioned panels.

The development of effective recycling methods thus contributes to reducing environmental impact and supports the principles of a circular economy.

Results and Discussion

Well-organized product management in renewable energy helps bridge the gap between innovation and the market. Product managers ensure that products meet consumer requirements, which accelerates their adoption and improves competitive positioning. Market research, a focus on client needs, market entry planning, and continuous product improvement all play a crucial role in enhancing product appeal and perception [4]. Key strategies for improving the efficiency of product management in renewable energy are presented in Table 1.

Table 1. Strategies for improving the efficiency of product management in renewable energy [5].

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Strategy	Description	Key Elements
Research and Development (R&D)	Continuous technological development requires investment in research and development. Collaboration with scientific organizations and industry experts, along with systematic tracking of technological trends, enables the identification and implementation of innovative solutions that enhance efficiency and sustainability.	- Partnership with scientific organizations - Analysis and implementation of technological trends - Investment in research and development
Effective Project Management	Successful project management requires a clear structure, including the establishment of specific goals and adaptive methodologies (e.g., Agile or Scrum). Regular progress assessment helps track task completion and achieve set goals, ensuring timely product release.	- Setting measurable goals - Application of adaptive methodologies (Agile, Scrum) - Ongoing monitoring and assessment of task completion
Supply Chain Optimization	A reliable supply chain ensures uninterrupted production and compliance with environmental standards. This includes building partnerships with suppliers, implementing monitoring systems, and using local resources to reduce logistical risks and the carbon footprint.	- Partnerships with suppliers - Monitoring and control systems - Localization of supply and engagement of local resources
Development of Strategic Partnerships	Partnerships in renewable energy allow for resource and risk sharing, accelerating product development and market entry. Joint projects with partners also facilitate regulatory compliance, which is particularly important given strict environmental standards.	- Resource and risk sharing - Joint development and market launch - Alignment with renewable energy regulatory requirements

The acceleration of the transition to clean energy, supported by product lifecycle management (PLM), has become a crucial factor in the energy sector, despite resource crises, inflationary pressures, and geopolitical instability. Demand for electricity is projected to triple by 2050 [5] due to rising living standards and industrial production. A key aspect of advancing this transformation is the use of digital technologies for managing product data in the solar, wind, and nuclear energy sectors. Companies that effectively handle data at all stages of the product lifecycle not only gain a competitive advantage but also unlock opportunities for scaling and transformation by integrating digitalization processes into a sustainable business model.

PLM, often associated with engineering solutions and automation systems, represents a comprehensive approach to managing all stages of a product's lifecycle, from concept to disposal. This approach integrates information management, customer interaction, operational processes, and supplier coordination. Companies implementing PLM can systematize data, enhance innovation potential, and ensure alignment between production and operational processes.

Wind turbine manufacturers use PLM to manage all product components—from design to maintenance. Supply chains involving thousands of suppliers are automated through PLM solutions, allowing for the maintenance of up-to-date material specifications and equipment configurations at all lifecycle stages. The creation of digital twins for after-sales service enhances equipment efficiency and provides data for upgrades and new product development.

Companies manufacturing solar panels are also actively leveraging PLM to ensure sustainable design and implement recycling programs. Research indicates that recycling outdated panels could yield assets worth up to 15 billion dollars by 2050 [5]. In Europe, the EU Directive on Waste Electrical and Electronic Equipment (WEEE) has established a recycling network for photovoltaic panels. However, many panels require high-temperature recycling due to complex polymer layers, presenting a challenge to develop more environmentally friendly solutions.

Recent events have underscored the importance of diversifying energy sources. The renewed interest in nuclear energy, capable of meeting low-carbon power needs, is supported by its ability to safely complement renewable sources. The development

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of small modular reactors (SMRs) has emerged as a promising technology that significantly reduces capital costs and risks. Companies like NuScale Power and GE-Hitachi are already investing in PLM, which enables configuration control and interaction with digital twins at every stage of production and operation.

Reducing the Carbon Footprint and Transitioning to Zero Waste. Wind and solar companies strive to minimize their carbon footprint by carefully managing materials and recycling up to 99% of components. Turbine manufacturers, such as Vestas, apply circular design concepts, aiming for zero-waste turbine production by 2040 [5].

The Role of PLM in Building a Sustainable Energy System. Effective PLM use promotes the digitalization of processes and coordination between a company's functional departments and supply chain. This creates a unified data system that supports environmentally responsible decisions at all stages of the product lifecycle—from raw material extraction to disposal.

The energy market, on the brink of profound changes, is rapidly adapting to new conditions where sustainability and low-carbon technologies are becoming the norm. In this context, PLM is integral to the transition to renewable and sustainable energy, laying a foundation for a low-carbon future and enhancing outcomes for businesses, customers, and the environment for years to come [5].

Product lifecycle management (PLM) in green energy includes stages such as planning, design, implementation, and support, where managers must consider environmental aspects that require a comprehensive approach. Table 2 below presents examples and approaches used by companies at various stages of the product lifecycle in the field of renewable energy.

Table 2. Examples and approaches of companies at various stages of the life cycle of products in the field of renewable energy [6-9].

Lifecycle Stage	Practical Example	Approaches and Benefits
Planning and Design	Ørsted (wind energy) has implemented "green planning" focused on minimizing carbon emissions at the turbine design stage.	- Assessment of environmental standards and resource needs - Reduction of environmental footprint - Cost optimization through the use of renewable resources
Production and Supply	Siemens Gamesa uses recyclable materials to manufacture wind turbines and designs components for reuse.	- Selection of eco-friendly materials - Reduced production costs - Waste reduction and increased sustainability of production processes
Operation and Support	Tesla uses a "digital twin" model for energy storage, which enables maintenance optimization and failure prevention.	- Monitoring and optimization of maintenance - Extension of equipment lifespan - Reduction in operating costs
End-of-Life and Recycling	First Solar fully recycles decommissioned solar panels, reclaiming up to 90% of materials, which minimizes environmental impact and reduces disposal costs.	- Implementation of recycling and disposal - Reduction in disposal costs - Product and company sustainability maintained through material reuse

Table 3 below outlines the advantages and disadvantages of product lifecycle management in green energy using a product-oriented approach.

Table 3. Advantages and disadvantages of product lifecycle management in the field of green energy using a product approach [8].

Aspect	Advantages	Disadvantages
Focus on Sustainability	Considering environmental factors at all product lifecycle stages helps reduce carbon	Requires complex lifecycle analysis and consideration of numerous environmental

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	footprint and resource consumption.	factors.
Adaptive Planning	Flexibility in adjusting strategies allows for rapid adaptation to market and regulatory changes.	Challenges in long-term planning due to rapidly changing technologies and market demands.
Customer Orientation	Rising demand for eco-friendly products is addressed, increasing customer loyalty.	Additional resources needed for consumer preference and trend research.
Innovative Development	Encourages the development and adoption of new technologies and solutions for improved product sustainability.	High costs for research, development, testing, and certification of new solutions.
Risk Reduction	Enables early identification and mitigation of environmental and regulatory risks during product development.	Increases the duration and complexity of initial analysis and planning stages.
Economic Efficiency	Resource and energy optimization reduces production and operating costs of products.	High initial investments in sustainable technologies and processes.
Reputational Advantages	Enhances public perception of the company as a responsible player in environmentally sensitive sectors.	Failure to achieve environmental goals may lead to criticism and loss of trust.

Thus, the application of product lifecycle management in green energy contributes to both economic and environmental efficiency, making products more sustainable at every stage. Organizations that implement this approach benefit from cost savings and a reduced carbon footprint, making their products more competitive and environmentally responsible.

Conclusion

The research findings indicate that product lifecycle management (PLM) in green energy plays a strategic role in achieving environmental and economic goals. Applying PLM at each stage of the product lifecycle—from planning and design to disposal—enables companies not only to reduce their carbon footprint but also to optimize production processes by increasing recycling rates and minimizing resource costs. Examples of PLM implementation by leading companies such as Ørsted and Siemens Gamesa demonstrate that the integration of digital technologies and circular economy principles enhances competitiveness, adaptability to changing market demands, and long-term business sustainability.

Moreover, PLM helps establish closed-loop supply chains where environmental efficiency is maintained at all stages of product creation and operation. The adoption of digital solutions, such as digital twins and automated monitoring systems, allows companies to more accurately control processes, adjust strategies in a timely manner, and allocate resources effectively.

Thus, product lifecycle management in green energy serves as a significant factor in sustainable development, fostering environmental responsibility and supporting the integration of innovations.

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