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The Role of Energy Efficiency in Sustainable Power Engineering

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Abstract
The greening of power engineering is a crucial element of the global strategy for ecologically sustainable development and serves as a foundational pillar of the European Union's sustainable energy policy. A key area of focus within this strategy is the improvement of power generation and consumption efficiency. These efforts aim to enhance the efficiency of energy conversion processes in power generation and to reduce energy consumption among end-users. Such initiatives are essential for decreasing the reliance on fossil fuels, ensuring energy security for nations, and mitigating climate change through the reduction of greenhouse gas emissions. This paper seeks to outline the primary strategies and actions undertaken to green the power engineering sector, with a specific focus on improving energy efficiency. It explores the functional principles of the systems and mechanisms that support these greening efforts in Germany, a country recognized for its leadership in sustainable energy practices. The discussion covers various approaches, including technological innovations, policy measures, and regulatory frameworks designed to optimize energy efficiency in both power generation and consumption. Furthermore, the paper examines how these actions contribute to broader international efforts to combat climate change and promote sustainable development. By focusing on Germany as a case study, the paper provides insights into the practical application of energy efficiency strategies within the power engineering sector, offering lessons that could be applied in other regions. This paper highlights the critical role of energy efficiency in the greening of power engineering, emphasizing its importance for achieving long-term sustainability goals. The findings underscore the need for continued investment in and commitment to energy efficiency measures as part of a comprehensive approach to sustainable energy policy and environmental protection.
Keywords: Energy Efficiency, Sustainable Power Engineering, Greening Strategies
JEL Codes: Q42, Q48, L94

1. INTRODUCTION

The future of power engineering is a critical issue in both national and global politics. This concern stems not only from the energy sector's role in accelerating climate change but also from the growing need to ensure an adequate energy supply for future societal demands. Energy accessibility is a fundamental driver of both economic and societal development. Projections suggest that by 2050, global energy consumption will need to increase by 2.5 to 3 times compared to 2010 levels (Nowicki, 2012). As technological advancements drive civilization forward, they also intensify the environmental impacts associated with energy production. To mitigate these negative effects, the concept of sustainable development, or eco-development, gained widespread recognition and support during the 1992 UN Conference on Environment and Development in Rio de Janeiro. This framework emphasizes balancing economic growth with environmental responsibility. According to the Environmental Protection Act (Dz. U., 2017), sustainable development is a comprehensive process that harmonizes political, economic, and social actions with the need to maintain a healthy and balanced environment. This concept emphasizes the importance of ensuring that the exploitation of natural resources is done in a way that allows for the continued functioning of essential natural processes, such as air and water cycles, biodiversity, and ecosystem health. The goal is to create a system where the current needs of individuals and societies are met without jeopardizing the ability of future generations to meet their own needs.

Sustainable development requires thoughtful long-term planning and responsible resource management to ensure economic growth is balanced with environmental protection. This includes promoting renewable energy sources, minimizing waste and emissions, preserving natural habitats, and fostering practices that reduce the ecological footprint. The integration of sustainability into social and economic policies helps create resilient communities and economies that are capable of thriving within the ecological limits of the planet. Furthermore, sustainable development is not only about environmental concerns but also about social equity and economic stability. It seeks to improve the quality of life for all people, reducing poverty and inequality while ensuring that economic growth is inclusive and environmentally responsible. By prioritizing a balance between these pillars—social, economic, and environmental—sustainable development aims to create a fairer, more prosperous, and sustainable future for both current and future generations. A crucial aspect of achieving this global eco-development strategy, and a cornerstone of Europe's sustainable energy policy, is the commitment to "greening" power engineering. This involves implementing initiatives focused on minimizing the adverse environmental impacts of power generation processes. The shift towards greener energy practices aims to reduce harmful emissions, lower pollution levels, and mitigate the overall ecological footprint of energy production. By transitioning to renewable energy sources such as wind, solar, and hydropower, and adopting

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energy-efficient technologies, the environmental burden of traditional energy production methods, such as fossil fuel combustion, can be significantly reduced.
These actions not only address the immediate environmental challenges, such as air and water pollution, but also contribute to long-term global efforts to combat climate change. Greening power engineering also encompasses investments in research and innovation to develop cleaner technologies, enhance energy efficiency, and ensure that future energy systems are both reliable and sustainable. In the European context, this approach is vital to meeting ambitious climate goals, such as reducing greenhouse gas emissions and achieving carbon neutrality. By integrating eco-friendly practices into energy policy, Europe is working to ensure a sustainable energy future that supports economic growth while protecting the environment for future generations. In the process of greening power engineering, actions aimed at improving energy efficiency play a vital role. Enhancing energy efficiency not only increases the effectiveness of energy transformation in power generation processes but also reduces overall energy consumption by end users. By optimizing how energy is produced, transmitted, and consumed, significant reductions in waste and emissions can be achieved, leading to a more sustainable and cost-effective energy system. Energy efficiency measures include the adoption of advanced technologies that allow for more efficient energy conversion, the modernization of outdated infrastructure, and the implementation of smarter energy management systems. These initiatives enable power plants to generate more energy from the same amount of resources, thus reducing fuel consumption and emissions. On the consumer side, energy-efficient appliances, buildings, and industrial processes can drastically lower energy demand without compromising functionality or comfort. Ultimately, improving energy efficiency supports the broader goals of sustainable development by reducing the strain on natural resources, minimizing environmental impacts, and helping to create a more resilient energy system capable of meeting future demands with fewer resources.

2. GREENING POWER ENGINEERING

The power generation sector holds a critical position in the economy, as the nation's energy security relies heavily on its efficient operation and performance. The products and services provided by this sector have a significant impact on nearly all other economic activities, influencing industries, transportation, and households. However, conventional power generation methods, particularly those relying on coal-fired power plants, contribute substantially to environmental degradation due to the burning of fossil fuels. These processes release large amounts of pollutants, including carbon dioxide, sulfur dioxide, and particulate matter, which negatively affect both the environment and public health. In response to these challenges, large-scale global initiatives focused on environmentally sustainable solutions, or the "greening of power engineering," are being implemented. These efforts aim to mitigate the harmful environmental impacts of energy production while ensuring long-term benefits for the environment, human health, and societal development. The greening of power engineering involves a broad array of strategies, including transitioning to renewable energy sources, increasing energy efficiency, and adopting cleaner technologies in power generation.
The term "greening of power engineering" refers to a comprehensive set of activities designed to minimize the environmental footprint of energy generation and consumption processes. This includes efforts to reduce greenhouse gas emissions, enhance the use of renewable energy like wind, solar, and hydroelectric power, and promote energy conservation among consumers. By embracing these eco-friendly practices, the power generation sector can contribute to a more sustainable future, improving both environmental conditions and the quality of life for present and future generations. The greening of power engineering is not only imperative but also a fundamental requirement for achieving sustainable power generation and ensuring global energy and environmental security. This transformation necessitates replacing traditional models of energy production and technologies that pose environmental risks with environmentally friendly power generation systems, specifically those based on clean energy, such as renewable energy sources. Developing a framework for clean energy production—often referred to as eco-energy—represents the future of sustainable power engineering.
Currently, these initiatives are a key focus of the European Union’s environmental policy. The primary goals include improving environmental quality, addressing climate change, ensuring the competitiveness of EU member states, enhancing energy security through the diversification of energy sources, and creating opportunities for local community growth by expanding labor markets, particularly through the use of decentralized renewable energy systems. This shift not only contributes to environmental sustainability but also provides economic benefits, especially for rural and underdeveloped regions that can tap into locally available renewable energy resources. The central tool for achieving the greening of power engineering is the adoption of clean energy technologies (CET). These technologies are designed to be low- or zero-emission, and their implementation is essential for drastically reducing the environmental impact of the power generation sector. Clean energy technologies encompass a wide range of innovations, including wind, solar, hydroelectric, and bioenergy, all of which help transition away from fossil fuel dependence. By incorporating clean energy technologies, nations can move towards a more sustainable energy model, one that aligns with global environmental objectives while providing economic resilience and long-term energy security. This transition is reinforced by regulatory frameworks and policy initiatives that prioritize sustainability, fostering a greener and more prosperous future for all.
Regulations concerning the greening of power engineering play a crucial role in advancing clean power technologies and meeting the obligations outlined in the EU Climate and Energy Package. These regulations are driving the large-scale development and implementation of clean energy technologies in the power sector, helping to address local environmental pollution by significantly reducing harmful emissions such as sulfur dioxide (SO2), nitrogen oxides (NOx), carbon dioxide (CO2), and particulate matter from coal-fired power plants. One of the key strategies for

minimizing the environmental impact of coal-based power generation involves integrating advanced technological solutions. This includes the enrichment of coal, clean combustion techniques, and the implementation of exhaust gas cleaning technologies. These combined approaches can significantly reduce the negative environmental effects associated with traditional coal power generation, making it more sustainable and environmentally friendly. In recent years, there has been a notable shift in the domestic power generation sector, with a growing reliance on renewable energy sources for electricity production. Additionally, there has been an increase in electricity generation from natural gas through gas-fired power plants, which typically emit fewer pollutants compared to coal-fired plants. This trend reflects a broader global movement toward cleaner, more sustainable energy solutions that align with environmental protection goals and contribute to the overall greening of the energy sector. The ongoing transition toward renewable energy and cleaner technologies is essential for reducing the ecological footprint of the power generation industry and ensuring a sustainable energy future. These efforts not only support the reduction of greenhouse gas emissions but also contribute to improving air quality, enhancing energy security, and promoting economic growth through the development of green jobs and innovation in the energy sector.

3. DISCUSSION

The Energy Efficiency Act defines energy efficiency as “the ratio of the achieved utility effect for a particular facility, technical device, or plant under typical use or operating conditions to the energy consumed by that facility, device, or plant, or as a result of a service rendered necessary to bring about such an effect” (Dz. U., 2016). Essentially, this refers to how effectively energy is used to produce the desired outcome with minimal waste. The energy efficiency target set within this framework aimed to reduce primary energy consumption by 13.6 million tonnes of oil equivalent (Mtoe) between 2010 and 2020. Achieving this target reflects an improvement in energy efficiency, even in the context of economic growth, where energy demand typically rises. This goal was outlined in terms of both primary and final energy consumption, with specific benchmarks set for the total amount of energy used by the end of 2020. This target emphasizes the importance of energy conservation and optimization across sectors to ensure sustainable economic and environmental outcomes. Germany's energy efficiency targets for 2020 were established based on data from analyses and projections outlined in the governmental document “Germany Energy Policy until 2030.” These analyses suggest that the reduction in primary energy consumption will be driven by a combination of previously implemented measures and newly introduced activities aimed at improving energy efficiency, as outlined in the country’s national energy policy.

A key indicator of energy efficiency in the generation of heat and electricity is the efficiency of fuel energy conversion. This metric is particularly significant from both energy utilization and ecological perspectives. The more efficient the conversion process, the less fuel is required, leading to lower overall fuel demand. This directly results in reduced operating costs for power plants and industrial facilities, as well as lower emissions, contributing to environmental protection efforts. At the energy consumption stage, the potential for improving energy efficiency depends on the gap between "actual losses"—which are influenced by factors such as managerial expertise, the condition and performance of equipment, and the financial state of the user—and "unavoidable" energy losses, which are inherent to even the most advanced devices and processes available (Fryc et al., 2012). Closing this gap requires both technological advancements and better management practices, creating opportunities to reduce energy waste and enhance overall efficiency in various sectors. According to the 2010 Directive on the indication of energy and resource consumption through labeling and standardized product information for energy-related products (European Commission, 2010), as well as the Act of 14 September 2012 concerning the obligation to provide information on energy consumption for energy-using products (Dz. U., 2012), all energy-using products must include a label that specifies the device’s energy efficiency and annual energy consumption. This labeling ensures that consumers are informed about the energy performance of the products they purchase, contributing to better decision-making and promoting energy conservation.

The final energy savings achieved through completed energy efficiency projects are verified by the issuance of an energy efficiency certificate, granted by the President of the Energy Regulatory Office (URE). These certificates serve as proof of energy savings and are equivalent to acquiring property-related rights for the projects undertaken by the respective entities. The procedure for awarding energy efficiency certificates follows the guidelines established under the former Energy Efficiency Act of 2011 (Dz. U., 2011). According to this Act, the President of the URE conducts tenders at least once a year to select eligible energy efficiency projects for certification. Entities wishing to participate in these tenders must submit a properly completed tender declaration, along with an energy efficiency audit of the support projects mentioned in the declaration. This system ensures that only verified energy-saving projects receive certification, encouraging investment in energy efficiency improvements and helping the country meet its broader sustainability goals. The combination of clear labeling requirements and the certification process supports the promotion of energy-efficient products and technologies, driving progress toward a more sustainable energy future. Information regarding the issuance of energy efficiency certificates, along with the corresponding energy efficiency audit card, is made publicly available by the President of the Energy Regulatory Office (URE) through the Public Information Bulletin of the URE. The entity that wins the tender organized by the President of the URE submits an application for the issuance of an energy efficiency certificate, which verifies the declared energy savings achieved through specific energy efficiency improvement measures.

To receive what are known as "white certificates," an application for an energy efficiency certificate, along with the completed energy efficiency audit, must be submitted to the President of the URE. The white certificate system, revised under the new Energy Efficiency Act, has simplified the process for obtaining these certificates. Previously, tenders were held once a year by the President of the URE; however, under the new system, applications are accepted on a continuous basis. Decisions regarding the issuance of energy efficiency certificates are now made within 45 days, streamlining the procedure and making it more accessible to participating entities. An additional key aspect of this system, which promotes pro-environmental activities related to improving energy efficiency in energy production, distribution, and usage, is the company energy audit. This audit is conducted by an entity independent of the company being audited, which possesses the required knowledge and professional expertise to perform the audit. Alternatively, a qualified expert from within the company may conduct the audit, provided they are not directly involved in the activities being audited. This process ensures the accuracy and reliability of energy efficiency assessments and supports ongoing efforts to enhance energy conservation across sectors. The first company energy audit was required to be completed by 30 September 2017, within 12 months of the Energy Efficiency Act's enactment on 20 May 2016 (ME, 2016). Upon completing the audit, the business is obligated to notify the President of the Energy Regulatory Office (URE) within 30 days. This notification must include information regarding potential energy savings identified during the audit. The President of the URE is further required to report annually to the Minister of Energy by 31 January of the following year. This report must contain data on the number of company energy audits conducted, the number of businesses that completed these audits, and the possible energy savings identified. If a company fails to fulfill the obligation to conduct an energy audit, the President of the URE may impose a financial penalty, which can amount to up to 5% of the company's income from the previous tax year. When determining the penalty, the President of the URE considers factors such as the severity of the violation, the frequency of repeated non-compliance, and the financial capacity of the business being penalized. Company energy audits play a crucial role in supporting energy efficiency improvement efforts. These audits provide businesses with valuable insights into potential energy savings and can be used for future analyses and inspections to optimize energy usage. By identifying areas where energy efficiency can be enhanced, audits help companies reduce operating costs, minimize environmental impacts, and improve overall sustainability.

4. CONCLUSION

Activities aimed at improving energy efficiency in both the generation and utilization of energy are a vital component of projects carried out under the umbrella of clean energy technologies. These initiatives can be applied across various sectors of the economy, including industry, transportation, residential, and commercial buildings. By enhancing energy efficiency, these projects contribute to reducing energy waste, lowering greenhouse gas emissions, and optimizing the use of available resources. In the industrial sector, for example, energy efficiency improvements may involve upgrading machinery, refining production processes, or incorporating automation technologies. In transportation, it can mean transitioning to electric vehicles or enhancing public transport systems. In residential and commercial settings, energy efficiency measures might include better insulation, the use of smart energy management systems, and the adoption of energy-efficient appliances. Ultimately, these energy efficiency activities not only support environmental sustainability but also provide economic benefits by reducing energy costs and improving the competitiveness of businesses. The widespread implementation of such measures is essential for meeting global climate goals and ensuring a sustainable energy future.

In the power sector, modernization investments are crucial for enhancing energy efficiency, particularly in countries like Germany, where over 60% of energy is generated in power plants that were installed more than 25 years ago. Aging infrastructure tends to be less efficient and more environmentally harmful compared to modern technologies. These older power blocks often have lower fuel conversion efficiency, resulting in higher fuel consumption and greater emissions of pollutants such as CO2, sulfur dioxide, and nitrogen oxides. To address these challenges, investments in upgrading or replacing outdated power plants with more efficient and cleaner technologies are essential. This can include retrofitting existing facilities with advanced systems for better fuel conversion, integrating renewable energy sources, and adopting cutting-edge technologies like combined heat and power (CHP) systems or carbon capture and storage (CCS) solutions. Such investments not only reduce environmental impacts but also improve the reliability and economic performance of the energy sector. By prioritizing modernization efforts, Germany can significantly enhance the efficiency of its power generation, contribute to reducing greenhouse gas emissions, and meet its long-term sustainability and energy security goals. Improving energy efficiency in power generation systems within the power sector, optimizing industrial processes across various industries, and rationalizing the final use of energy are expected to deliver numerous benefits. These include significant energy savings across all stages of the energy supply chain, from generation and transmission to end-user consumption.

In the power generation stage, increased efficiency reduces the amount of fuel required to produce energy, leading to lower operating costs and a decrease in harmful emissions. Upgrading transmission systems minimizes energy losses during distribution, ensuring that more energy reaches consumers. Furthermore, rationalizing energy use by end consumers—whether in industrial, commercial, or residential settings—helps reduce overall demand, lessening the strain on energy resources and infrastructure. These improvements collectively contribute to reducing the ecological footprint of energy production, lowering greenhouse gas emissions, and supporting the transition to a more sustainable and resilient energy system. Additionally, the economic benefits include lower energy costs for both producers and consumers, enhanced competitiveness for businesses, and long-term savings that contribute to overall economic stability and environmental protection. The white certificate system is a key mechanism designed to support activities aimed at improving energy efficiency. This system incentivizes energy efficiency improvements by awarding certificates to entities that achieve verifiable energy savings through specific projects. To obtain white certificates, a detailed procedure must be followed, which includes conducting energy efficiency audits. These audits assess and confirm the effectiveness of the energy efficiency improvement measures that have been implemented. Once the audit verifies that the project has resulted in final energy savings, the white certificates are issued. These certificates not only serve as proof of the achieved energy efficiency but also provide financial benefits to the entities involved, as they can be traded or used to fulfill regulatory obligations. The system encourages continuous investment in energy-saving technologies and practices, fostering greater environmental sustainability while promoting economic efficiency in energy use across various sectors. The study indicates that energy efficiency improvement initiatives undertaken by power companies involved in energy generation, electricity, heat, or natural gas distribution, as well as those selling these resources to end users in Germany, result in significant ecological and economic benefits. These activities, along with efforts by final energy users connected to the grid, lead to measurable outcomes, such as the reduction of final energy consumption and a decrease in carbon dioxide emissions.

From an ecological perspective, these measures contribute to lowering greenhouse gas emissions, which is crucial for meeting climate goals and improving environmental health. Economically, reducing energy consumption helps lower operational costs for both providers and consumers, enhancing efficiency and competitiveness across industries. The combination of these benefits demonstrates the value of energy efficiency improvements not only for sustainability but also for the overall economy, as it reduces dependency on finite energy resources and mitigates the negative environmental impacts of energy production and use. Improving energy efficiency in energy generation and consumption systems is a key strategy for meeting the targets outlined in the EU climate and energy guidelines, including those for Germany. Achieving these goals requires the implementation of an integrated energy policy framework that emphasizes the necessity for a new industrial revolution. This revolution would drive significant changes in how energy is produced, managed, and consumed, focusing on more efficient and sustainable methods. The transition to cleaner and more efficient energy systems involves adopting advanced technologies, enhancing renewable energy integration, and optimizing energy use across sectors. It also calls for greater collaboration between industries, governments, and energy providers to reduce energy waste and emissions. By prioritizing energy efficiency improvements, Germany and other EU nations can effectively balance economic growth with environmental sustainability, while contributing to the long-term reduction of greenhouse gas emissions and fostering innovation in the energy sector.

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