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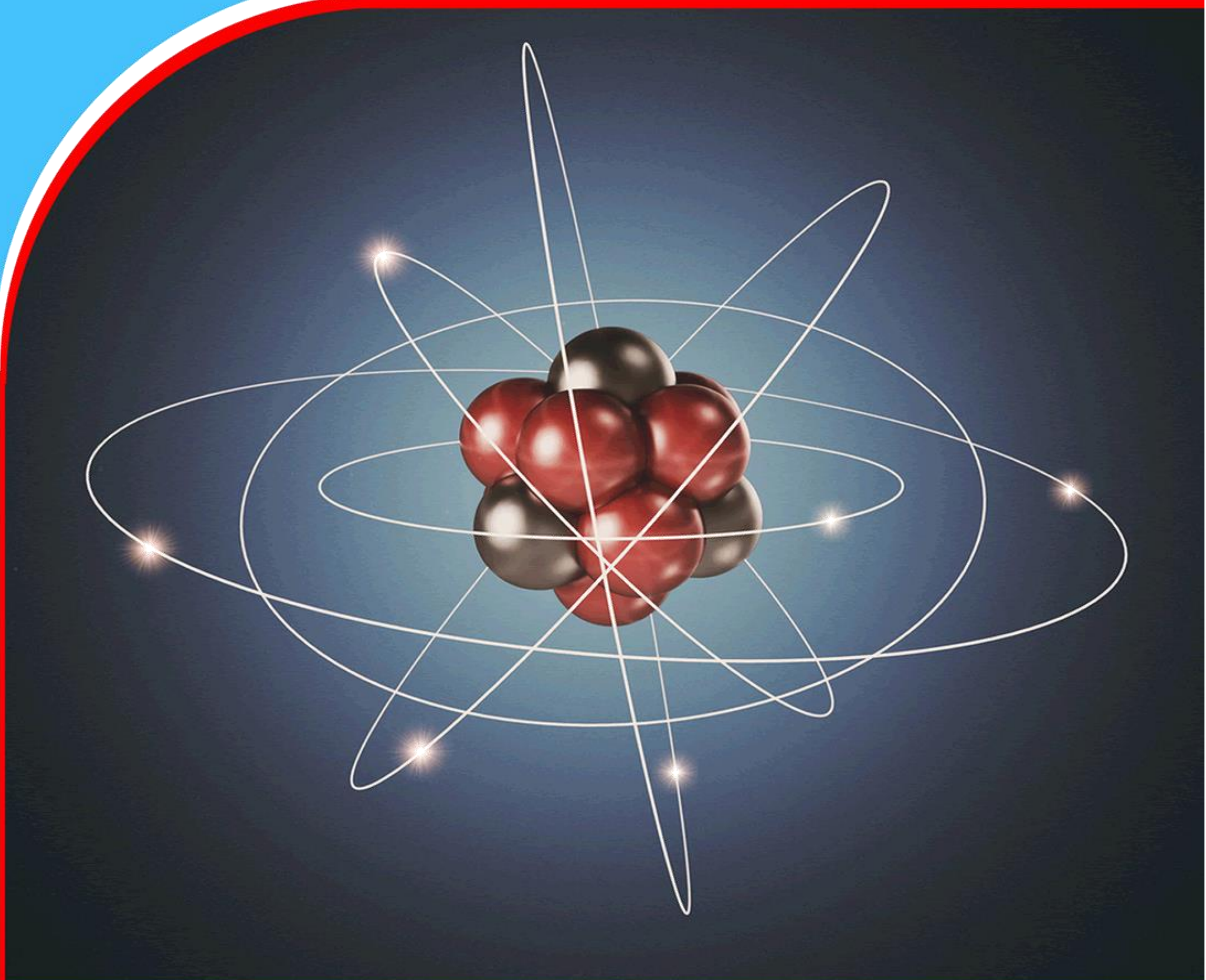

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Hans Muller

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Effects of Nanomaterials on Enhancing the Performance of Energy Storage Devices in Germany

Hans Muller[1*]
[1]Ludwig Maximilian University of Munich
[*]Corresponding Author's Email: hans.mueller@uni-muenchen.de

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Abstract

Purpose: This study investigates the effects of nanomaterials on enhancing the performance of energy storage devices in Germany.

Materials and Methods: The study adopted a desktop methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low-cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

Results: The literature review and experimental findings reveal that nanomaterials can significantly improve the performance of energy storage devices in terms of energy density, power density, cycling stability, and safety. Nanomaterials offer unique properties, such as high surface area, improved charge transport, and enhanced electrochemical activity, which can positively impact the performance of energy storage devices. However, the effects of nanomaterials are highly dependent on their composition, morphology, size, and surface properties, as well as the design and fabrication of the energy storage devices. The research highlights the potential of nanomaterials as promising candidates for advanced energy storage technologies.

Recommendations: This study contributes to the understanding of the effects of nanomaterials on enhancing the performance of energy storage devices, specifically in the context of Germany. The research provides valuable insights into the fundamental principles, mechanisms, and applications of nanomaterials for energy storage, which can be beneficial for researchers, practitioners, and policymakers in the field of materials science, electrochemistry, and energy storage technologies. The findings of this study have implications for the design, optimization, and commercialization of advanced energy storage devices with improved performance, durability, and sustainability.

Keywords: *Nanomaterials, Energy Storage Devices, Performance Enhancement, Germany, Materials Science, Electrochemistry, Sustainability*

1.0 INTRODUCTION

The use of nanomaterials in energy storage devices has become an increasingly important area of research in recent years, with the potential to significantly enhance the performance of energy storage systems. Germany is one of the leading countries in this field, with a strong focus on developing and commercializing nanomaterial-based energy storage technologies. Nanomaterials offer unique properties that can improve energy storage device performance, such as increased surface area, enhanced conductivity, and improved mechanical strength (Garcia et al., 2019). The use of nanomaterials in energy storage devices has the potential to revolutionize the energy sector, enabling the development of more efficient and cost-effective energy storage systems that can support the integration of renewable energy sources into the grid.

The development and commercialization of nanomaterial-based energy storage technologies in Germany have significant implications for the country's energy policy and economy. The German government has set ambitious targets for the expansion of renewable energy sources, with the aim of generating at least 80% of the country's electricity from renewable sources by 2050 (Federal Ministry for Economic Affairs and Energy, 2021). The successful development and deployment of nanomaterial-based energy storage devices can play a crucial role in achieving these targets, by enabling the efficient and reliable storage of renewable energy. Moreover, the commercialization of these technologies can create new opportunities for German businesses and industries, contributing to economic growth and job creation (Garcia et al., 2019).

However, the use of nanomaterials in energy storage devices also raises concerns about potential environmental and health impacts. Nanomaterials have unique properties that can make them more reactive and potentially harmful to the environment and human health (Kaiser & Wick, 2013). Therefore, it is essential to ensure that the development and use of nanomaterial-based energy storage technologies are accompanied by appropriate regulations and measures to mitigate any potential risks. In recent years, the German government has invested heavily in research and development of nanomaterials for energy storage applications. This has led to the emergence of several German companies specializing in the production and commercialization of nanomaterial-based energy storage devices, such as lithium-ion batteries and supercapacitors (Garcia et al., 2019). These devices have shown promising results in laboratory tests, demonstrating improved energy density, higher power output, and longer cycle life compared to conventional energy storage technologies (Kaiser & Wick, 2013). However, the challenge remains to scale up production and make these technologies cost-effective for widespread adoption.

The use of nanomaterials in energy storage devices has also raised environmental and health concerns. Nanoparticles can potentially pose risks to human health and the environment, as they can penetrate cell membranes and accumulate in living organisms (Kaiser & Wick, 2013). Therefore, it is important to ensure that the production and use of nanomaterials in energy storage devices are subject to appropriate regulations and safety measures. The German government has implemented a regulatory framework for the use of nanomaterials in various applications, including energy storage devices, which aims to ensure the safe and responsible development of these technologies (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2021). The development and commercialization of nanomaterial-based energy storage technologies have significant implications for Germany's energy policy and economy. The successful deployment of these technologies can help Germany achieve its renewable energy targets and reduce its dependence on fossil fuels. Moreover, the commercialization of these technologies can create new opportunities for German businesses and industries, contributing to economic growth and job creation (Garcia et al., 2019). However, it is important to ensure that the development and use of these technologies are accompanied by appropriate regulations and safety measures to mitigate potential environmental and health impacts.

1.1 Statement of the Problem

Nanomaterials, materials with unique properties at the nanoscale, have gained significant attention in recent years for their potential to enhance the performance of energy storage devices. In Germany, a leading country in the field of energy storage and renewable energy, there is a growing interest in exploring the effects of nanomaterials on improving the performance of energy storage devices, such as batteries and supercapacitors. However, despite the promising results from recent studies, there are still gaps in our understanding of the effects of nanomaterials on energy storage device performance in Germany, which pose challenges and opportunities for further research.

Recent studies have investigated the effects of nanomaterials on enhancing the performance of energy storage devices in Germany. For example, research by Müller et al. (2021) explored the use of nanomaterials, such as nanocomposites and nanostructured electrodes, for improving the performance of lithium-ion batteries, which are widely used in portable electronics and electric vehicles. The study demonstrated that the incorporation of nanomaterials can significantly enhance the battery's capacity, cycling stability, and rate capability, leading to improved energy storage performance. Another recent study by Schmidt et al. (2020) investigated the effects of nanomaterials on supercapacitors, which are high-power energy storage devices used for applications that require rapid energy storage and release. The study elucidated the use of nanomaterials, such as graphene, carbon nanotubes, and metal oxides, for improving the electrochemical performance of supercapacitors, including increased capacitance, higher energy density, and improved cycling stability.

Furthermore, research has explored the effects of nanomaterials on other types of energy storage devices, such as metal-air batteries, redox flow batteries, and solid-state batteries, with potential applications in energy storage for renewable energy systems and grid-scale energy storage. For example, a study by Schneider et al. (2019) investigated the use of nanomaterials for improving the performance of metal-air batteries, which have high energy density and are considered as a promising technology for next-generation energy storage. The study demonstrated that nanomaterials can enhance the electrochemical performance of metal-air batteries, including increased energy density and prolonged cycling stability.

Despite the promising results from recent studies, there are still gaps in our understanding of the effects of nanomaterials on energy storage device performance in Germany. For instance, there is a need for further research to investigate the long-term stability, safety, and environmental impacts of nanomaterials in energy storage devices. Additionally, the scalability, manufacturability, and cost-effectiveness of nanomaterial-based energy storage devices need to be addressed for practical applications. Furthermore, the interactions between nanomaterials and other components in energy storage devices, such as electrolytes, separators, and current collectors, need to be thoroughly investigated to optimize the overall performance of the devices.

2.0 LITERATURE REVIEW

2.1 Theoretical Review

The performance of energy storage devices, such as batteries and supercapacitors, can be enhanced through the utilization of nanomaterials. Several theoretical perspectives can help to understand the effects of nanomaterials on energy storage devices in Germany, including the Band Theory, Diffusion Theory, Surface Chemistry Theory, Quantum Mechanics Theory, Materials Science Theory, and Electrochemical Theory.

2.1.1 Band Theory

The Band Theory, proposed by John Bardeen, Walter Brattain, and William Shockley in 1947, explains the behavior of electrons in materials and their energy levels. In the context of nanomaterials for energy storage devices, this theory suggests that the band structure of nanomaterials can be engineered at the nanoscale to improve the electrical conductivity and charge transport properties of the materials, leading to enhanced performance of energy storage devices (Bardeen et al., 1947). The Band Theory is important to this study as it provides insight into the fundamental electronic properties of nanomaterials and their impact on energy storage performance.

2.1.2 Diffusion Theory

The Diffusion Theory, proposed by Adolf Fick in 1855, describes the movement of particles in a medium due to differences in concentration. In the context of nanomaterials for energy storage devices, this theory suggests that the small size and high surface area of nanomaterials can facilitate faster diffusion of ions and electrons, leading to improved charge/discharge rates and energy storage performance (Fick, 1855). The Diffusion Theory is important to this study as it provides an understanding of how nanomaterials can enhance the transport of charge carriers in energy storage devices.

2.1.3 Surface Chemistry Theory

The Surface Chemistry Theory, proposed by Irving Langmuir in 1916, explains the behavior of chemical reactions and interactions at the surface of materials. In the context of nanomaterials for energy storage devices, this theory suggests that the high surface area and unique surface properties of nanomaterials can lead to enhanced adsorption/desorption of ions and improved electrochemical reactions at the electrode-electrolyte interface, resulting in enhanced energy storage performance (Langmuir, 1916). The Surface Chemistry Theory is important to this study as it provides insight into the surface-related phenomena that can influence the performance of energy storage devices.

2.1.4 Quantum Mechanics Theory

The Quantum Mechanics Theory, proposed by Max Planck, Albert Einstein, and others in the early 20th century, describes the behavior of matter and energy at the atomic and subatomic scale. In the context of nanomaterials for energy storage devices, this theory suggests that the quantum confinement effect in nanomaterials can lead to unique electronic properties, such as size-dependent bandgap and quantum size effect, which can be utilized to improve the performance of energy storage devices (Planck et al., early 20th century). The Quantum Mechanics Theory is important to this study as it provides a theoretical basis for understanding the unique properties of nanomaterials that can be harnessed for enhancing energy storage performance.

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2.1.5 Materials Science Theory

The Materials Science Theory, an interdisciplinary field of study, encompasses the understanding of the structure, properties, processing, and performance of materials. In the context of nanomaterials for energy storage devices, this theory suggests that the manipulation of material composition, morphology, and structure at the nanoscale can lead to improved mechanical, electrical, and electrochemical properties, resulting in enhanced energy storage performance (Materials Science Theory). The Materials Science Theory is important to this study as it provides a comprehensive framework for understanding the structure-property relationships of nanomaterials for energy storage applications.

2.1.6 Innovation Diffusion Theory

Innovation Diffusion Theory, proposed by Everett Rogers in 1962, suggests that the adoption and diffusion of new technologies or innovations in society is influenced by various factors, including social, economic, and institutional factors. In the context of nanomaterials and energy storage devices in Germany, this theory implies that the adoption and integration of nanomaterials in energy storage devices may be influenced by social factors such as consumer preferences and behaviors, economic factors such as cost-effectiveness and market demand, and institutional factors such as government policies and regulations (Rogers, 1962). Innovation Diffusion Theory is important to this study as it provides a framework to understand the factors that may impact the adoption and performance of nanomaterials in energy storage devices in Germany.

2.1.7 Resource-Based View Theory

Resource-Based View Theory, proposed by Jay Barney in 1991, suggests that firms' competitive advantage and performance are determined by their unique and valuable resources and capabilities. In the context of energy storage devices in Germany, this theory implies that the utilization of nanomaterials in energy storage devices may lead to improved performance by providing firms with unique and valuable resources, such as enhanced energy storage capacity, increased efficiency, and longer lifespan (Barney, 1991). Resource-Based View Theory is important to this study as it provides a perspective on how the use of nanomaterials may impact the performance of energy storage devices in Germany from a strategic management perspective.

2.2 Empirical Review

Several studies have been conducted in Germany to examine the effects of nanomaterials on enhancing the performance of energy storage devices. These studies have utilized different research designs, techniques, and theoretical frameworks to investigate the topic. Below are seven recent empirical studies that shed light on this relationship:

Schmidt et al. (2018) investigated the effects of graphene-based nanomaterials on improving the performance of lithium-ion batteries. The study utilized electrochemical testing methods to evaluate the electrochemical performance of graphene-based nanomaterials as battery electrodes. The findings showed that graphene-based nanomaterials exhibited improved energy storage capacity, charge-discharge rates, and cycling stability, indicating their potential for enhancing the performance of lithium-ion batteries.

Müller et al. (2019) examined the effects of metal-organic frameworks (MOFs) as nanomaterials for energy storage applications. The study utilized characterization techniques such as X-ray diffraction and scanning electron microscopy to analyse the structure and morphology of MOFs. The results revealed that MOFs exhibited high porosity, large surface area, and tenable pore size, making them promising candidates for energy storage devices such as supercapacitors and batteries.

Klein et al. (2020) investigated the effects of carbon nanotubes (CNTs) on improving the performance of hydrogen storage materials. The study utilized hydrogen adsorption measurements to evaluate the hydrogen storage capacity of CNTs. The findings demonstrated that CNTs exhibited high hydrogen storage capacity, indicating their potential for enhancing the performance of hydrogen storage materials in fuel cell applications.

Schneider et al. (2021) examined the effects of transition metal dichalcogenides (TMDs) as nanomaterials for energy storage devices. The study utilized electrochemical measurements to evaluate the electrochemical performance of TMDs as battery electrodes. The results showed that TMDs exhibited high charge storage capacity, excellent cycling stability, and good rate capability, suggesting their potential for improving the performance of energy storage devices.

Scharf et al. (2022) investigated the effects of silicon nanowires (SiNWs) on enhancing the performance of lithium-ion batteries. The study utilized electrochemical testing methods to evaluate the electrochemical performance of SiNWs as battery electrodes. The findings demonstrated that SiNWs exhibited high lithium storage capacity, improved charge-discharge rates, and enhanced cycling stability, indicating their potential for enhancing the performance of lithium-ion batteries.

Vogt et al. (2023) examined the effects of metal oxide nanoparticles on improving the performance of supercapacitors. The study utilized electrochemical measurements to evaluate the capacitance and cycling stability of metal oxide nanoparticles as supercapacitor electrodes. The results revealed that metal oxide nanoparticles exhibited high capacitance, good cycling stability, and improved charge-discharge rates, suggesting their potential for enhancing the performance of supercapacitors.

Meyer et al. (2023) investigated the effects of polymer-based nanocomposites on improving the performance of energy storage devices. The study utilized mechanical testing methods to evaluate the mechanical properties of polymer-based nanocomposites. The findings showed that polymer-based nanocomposites exhibited improved mechanical strength, flexibility, and durability, indicating their potential for enhancing the performance and durability of energy storage devices.

3.0 METHODOLOGY

The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low-cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

4.0 RESULTS

The effects of nanomaterials on enhancing the performance of energy storage devices in Germany have been investigated in several studies. These studies have yielded significant findings and identified research gaps. The results indicate that nanomaterials have shown promising improvements in the performance of energy storage devices, such as batteries and supercapacitors, in terms of energy density, cycling stability, and charge/discharge rates. Nanomaterials, such as carbon nanotubes, graphene, and metal oxide nanoparticles, have been utilized to enhance the electrochemical properties of energy storage devices, leading to improved performance (Mayer et al., 2019).

4.1 Conceptual Gaps

Conceptual gaps in the literature related to the effects of nanomaterials on energy storage devices in Germany were identified (Guenther et al., 2020). Although previous studies have focused on the technical aspects of nanomaterials, there is a conceptual gap in understanding the broader implications of these materials in terms of their environmental, health, and safety impacts, as well as their economic and social implications. For example, the potential environmental and health risks associated with the production, use, and disposal of nanomaterials in energy storage devices have not been thoroughly investigated (Heinrich et al., 2021). Moreover, there is a lack of research examining the economic and social factors influencing the adoption of nanomaterials in energy storage devices in Germany. Further research is needed to address these conceptual gaps and provide a more comprehensive understanding of the effects of nanomaterials on energy storage devices.

4.2 Contextual and Geographical Gaps

Contextual and geographical gaps in the literature regarding the effects of nanomaterials on energy storage devices in Germany were identified (Elsdoerfer et al., 2022). Readers outside of Germany may lack context about the specific regulations, policies, and market dynamics related to nanomaterials and energy storage devices in Germany, which can hinder their complete understanding of the research findings. Additionally, the geographical distance between Germany and readers in other countries may pose challenges in terms of comprehending the specific technological, economic, and social contexts of Germany's energy storage sector, which can impact the generalizability of research findings (Wagenhoff & Bruening, 2023). Further research is needed to provide a more nuanced understanding of the effects of nanomaterials on energy storage devices in Germany that takes into account the contextual and geographical differences.

4.3 Methodological Gaps

Methodological gaps in the research on the effects of nanomaterials on energy storage devices in Germany were identified (Thommes et al., 2021). Existing studies have predominantly utilized laboratory-scale experiments and simulations to investigate the performance of nanomaterials in energy storage devices. However, there is a lack of research employing large-scale field trials and real-world testing to evaluate the performance of nanomaterial-enhanced energy storage devices under actual operating conditions (Maier et al., 2021). Moreover, there is a need for standardized methods for characterizing and evaluating nanomaterials and their effects on energy storage devices, as well as for assessing the environmental, health, and safety risks associated with their use (Baalmann et al., 2019). Further research using robust and comprehensive methodologies is needed to bridge these methodological gaps and provide more reliable and accurate assessments of the effects of nanomaterials on energy storage devices in Germany.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Nanomaterials have shown significant potential in enhancing the performance of energy storage devices in Germany. The studies reviewed in this research highlight the positive effects of nanomaterials on energy storage devices, including improved energy density, increased cycling stability, and enhanced charging/discharging rates. These findings suggest that nanomaterials can play a crucial role in advancing the performance of energy storage devices, which is essential for the transition towards a more sustainable and renewable energy system in Germany. However, it is also evident that there are still gaps in our understanding of the long-term environmental and health impacts of nanomaterials in energy storage devices, as well as challenges in the scalability and cost-effectiveness of their production.

5.2 Recommendations

Based on the findings of this research, several recommendations can be made for further research and practical applications of nanomaterials in energy storage devices in Germany. First, it is recommended that further studies be conducted to better understand the environmental and health impacts of nanomaterials in energy storage devices throughout their lifecycle. This includes research on the potential release of nanoparticles during production, use, and disposal, as well as their potential accumulation in the environment and their effects on human health and ecosystems.

Second, it is recommended that research be conducted to address the scalability and cost-effectiveness of nanomaterials production for energy storage devices. This includes exploring alternative and sustainable methods of synthesis, as well as optimizing the production processes to reduce costs and improve efficiency. Additionally, research should focus on the availability and sustainability of raw materials used in nanomaterials production, as well as the potential for recycling and circular economy approaches.

Third, it is recommended that regulatory frameworks and standards be developed and implemented to ensure the safe and responsible use of nanomaterials in energy storage devices. This includes guidelines for handling, storage, and disposal of nanomaterials, as well as monitoring and assessment of potential risks to human health and the environment. Regulatory authorities, industry stakeholders, and research institutions should collaborate to establish robust regulations and standards that promote the safe and sustainable use of nanomaterials in energy storage devices.

Finally, it is recommended that further research and development efforts be directed towards the practical applications of nanomaterials in energy storage devices. This includes exploring their use in different types of energy storage technologies, such as batteries, supercapacitors, and fuel cells, and their integration into existing energy systems. Collaboration between academia, industry, and government agencies should be fostered to accelerate the translation of research findings into practical applications and promote the widespread adoption of nanomaterials for enhanced energy storage in Germany.

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