Emerging Global Trends in the Potential of Nanotechnology for Achieving the Net Zero Goals

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Abstract. This article focuses on the serious time bound attempts of getting zero emissions for circular sustainability. It requires an all-encompassing strategy that prioritizes people, the planet, and profit. To achieve climate neutrality, nanotechnology is essential because it promotes the creation of cutting-edge, potentially game-changing technologies that have no negative effects on biodiversity and ecosystems. Nanotechnology is becoming increasingly environmentally friendly as the field turns its attention to renewable energy, waste diversion, digitalization, sustainable building construction, and structural engineering. Considering the United Nations Sustainable Development Goals and the European Green Deal, this article outlines essential steps towards reaching carbon neutrality. The transition to a sustainable future can be speed up if there is cooperation among local wisdom, businesses, and governments. Intelligent gadgets and building blocks have emerged as a central topic due to recent developments in nanotechnology. The paper emphasizes the potential of nanotechnology to generate innovation and sustainability and the importance of collaboration between different stakeholders.

Keywords: Nanotechnology · Climate Neutrality · Net Zero Goals · Green Energy · Waste Conversation

1 Introduction

The amount of greenhouse gases released into the environment must be equal to the amount withdrawn from the atmosphere known as net zero emissions. This can be done by engaging in activities like carbon sequestration or carbon offsetting, in addition to cutting back on emissions. The goal of reaching net zero emissions is often seen as necessary to limit global warming and mitigate the impacts of climate change [1, 2].

There are several emerging trends in nanotechnology that are being developed to help achieve the net zero goals set by countries and organizations around the world [3]. Some of these trends shown in Fig. 1 include carbon capture and storage, renewable energy, energy storage, energy efficiency, water purification, smart materials. Nanotechnology is being used to develop more efficient and cost-effective methods for capturing and storing carbon dioxide emissions from power plants and other industrial sources [4].

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It is being used to improve the efficiency and cost of solar cells, wind turbines, and other renewable energy technologies. Nanotechnology used to develop advanced batteries and other energy storage systems that can store energy generated from renewable sources for use when it is needed. It is also being used to develop more efficient heating and cooling systems, as well as more energy-efficient lighting and appliances [5, 6].

Nanotechnology is being used to develop advanced water filtration systems that can remove pollutants and impurities from the water, making it safer and more potable [7]. Smart materials are being developed using nanotechnology, which can change their properties in response to environmental changes, providing energy efficiency and sustainability benefits.

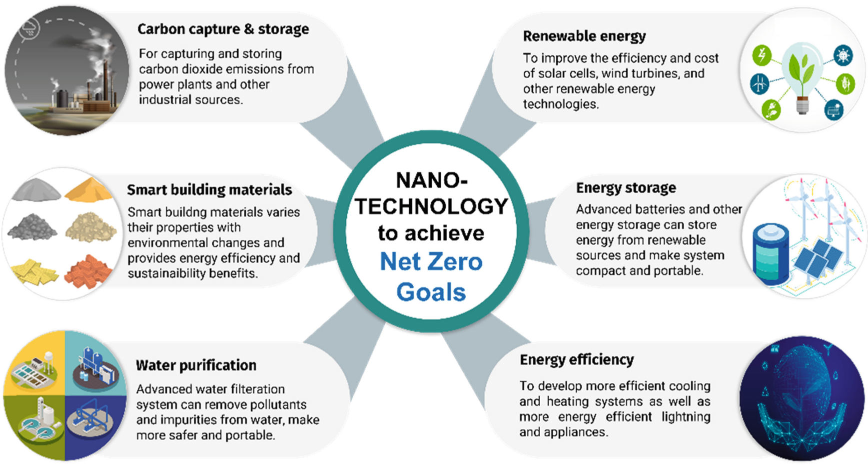

Fig. 1. Advancements in nanotechnology for supporting the net zero target emissions.

By utilising nanoparticles to catalyse chemical reactions, for example, nanotechnology can be utilised to increase the productivity of industrial processes. This has the potential to lessen the use of resources and the generation of trash during production. Air and water pollution can be mitigated with the use of nanotechnology. Nano-filters can be used to remove airborne contaminants while nanoparticles can be utilised to absorb them from water. Building insulation and energy efficiency can both be enhanced with the use of nanotechnology. For instance, by incorporating nanoparticles into construction materials, thermal conductivity can be increased, resulting in enhanced insulation and a decreased demand for heating and cooling systems [8–10].

The aforementioned nanotech trends have the potential to drastically cut GHG emissions, boost the usage of renewable energy, and facilitate the realisation of net zero goals established by nations and international organisations. Nanotechnology has the potential to improve many different industries, such as the medical, energy, and environmental sectors. Improvements in medication delivery, novel diagnostic tools and medical devices, and materials for tissue engineering and regenerative medicine [11] are all possible because to nanotechnology's application in the medical industry. Nanotechnology's applications in the energy sector include the development of novel materials for energy storage and generation, as well as the enhancement of existing solar cells, batteries, fuel cells and smart building structure. Nanotechnology has several potential applications in environmental technology, including the elimination of pollutants, the development of novel sensors and monitoring systems, and the design of new materials for the purification and treatment of water [8].

To keep detrimental effects on biodiversity and ecosystems to a minimum, however, nanotechnology must be developed and used in an environmentally responsible manner, just like any other technology. There may be a need for laws, monitoring, and risk assessments to make sure nanotechnology isn't having negative effects on people and the planet. Green nanotechnology research and development is crucial to ensuring that this promising field is developed in a way that protects biodiversity and natural systems [12].

Nanotechnology has the potential to significantly improve energy-efficiency and environmental performance in a variety of ways. However, it's important to note that further research and development is needed to fully realize these potential benefits and to ensure that the use of nanotechnology is safe and sustainable [12].

2 Net Zero Goals and Policies Modernization

The top 10 countries with the highest CO_2 emissions in the world with their population, Gross domestic product (GDP) and net zero target is shown in Fig. 2. The European Union's Emissions Database for Global Atmospheric Research (EDGAR), China produced 11680 million tons of CO_2 in 2020, followed by the US with 4535 million tons and India with 2412 million tons. However, these are also the world's three most populous countries, so their high CO_2 emissions mostly from transportation and electricity production can be attributed to their larger populations. When one balances the rankings by dividing total consumption by the country's population, the world's highest CO_2 emitters per capita are revealed per person [13].

The Paris Agreement requires net zero emissions by 2050 to prevent global warming to well below 2 °C. Energy, transportation, agriculture, and industry must significantly reduce greenhouse gas emissions to achieve this aim [13]. To achieve net zero emissions by 2050, countries must transition to clean and renewable energy sources, such as wind and solar power, and phase out fossil fuels. This may also require investment in new technologies such as carbon capture and storage and carbon offsetting, as well as changes in consumption patterns and lifestyle choices. Planting more trees and other plants to increase carbon absorption and lowering emissions are both crucial. It is crucial that targets be set and met at both the national and local levels of government in order to reach the target of net zero emissions [14]. The public can be educated and involved in the fight against climate change via means such as the establishment and enforcement of legislation and regulations, the provision of financial incentives for clean energy and energy efficiency, and the promotion of such. The world as a whole will need to work together to reduce emissions and transition to a low-carbon economy if we are to reach the goal of net zero emissions by 2050 [15, 16].

Updating the current policies to meet the problems of climate change and energy security is an essential part of modernising national climate and energy policies. Carbon

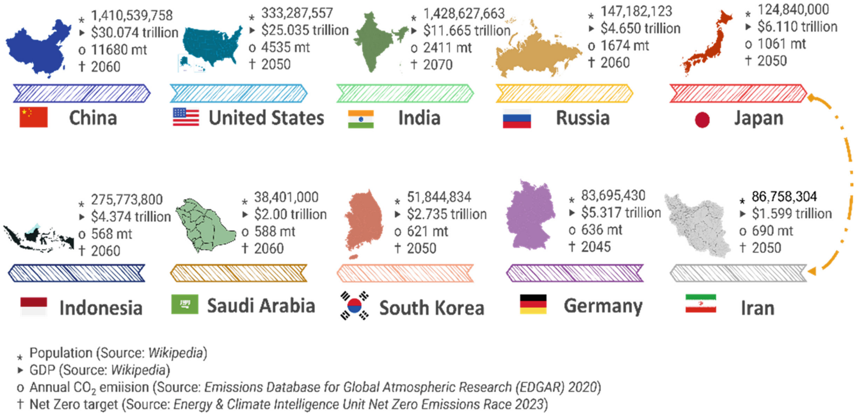

Fig. 2. Top 10 countries with the highest CO_2 emissions in the world with their population, GDP and the net zero targets

emission reduction strategies may include aggressive goal setting, the promotion of renewable energy sources, the implementation of energy efficiency measures, and the investment in cutting-edge technology [17].

A framework to lessen the negative effects of climate change on the economy and the populace, such as rising sea levels, higher average temperatures, and more frequent natural disasters, may also be required. To further ensure that the policies are successful, efficient, and egalitarian, the commercial sector, civic society, and academics might all be included in the policymaking process. The process of updating national climate and energy policy is intricate and varied, necessitating input from a wide variety of stakeholders and multiple tiers of government [18].

The green transformation can move along more quickly with consistent efforts and translational innovation. The term "translational innovation" describes the process of adapting theoretical findings and experimental results to real-world contexts. Examples of this would be the introduction of new legislation and regulations and the design of innovative business models. The government plays an integral role in fostering and supporting these endeavours through legislation, education, research, industrial infrastructure, trade policy, and the long-term goal of scientific groups. The adoption of sustainable practises by firms and individuals can be encouraged by government policies that provide out a roadmap for innovation and rollout [10].

Awareness and comprehension of climate change challenges, as well as the encouragement of the development of new technologies and solutions [17] can be aided by education and research. A faster green transition also requires the development of vital industrial infrastructure, such as renewable energy sources, energy storage, and smart grid technology. Facilitating the free movement of products and services across international borders is one way to speed up the spread of cutting-edge innovations. When it comes to keeping the scientific community abreast of the newest developments in the fields of climate change and sustainable development, scientific associations play a pivotal role in setting the long-term agenda of scientific research. Therefore, a convergence of government policy, education, research, industrial infrastructure, trade policy, and the long-term agenda of scientific associations can promote and accelerate the green transition.

3 SDGs and European Green Deal

The United Nations Sustainable Development Goals (UNSDGs) and the European Green Deal (EGD) outline several actions that nations can take to achieve carbon neutrality and address climate change. The UNSDGs include goal 13 which specifically calls for urgent action to combat climate change and its impacts. On the other hand, the European Green Deal (EGD) is the EU's plan to make the EU's economy sustainable by transforming climate and environmental concerns into opportunities across all sectors and improving the lives of EU residents.

Both frameworks provide a comprehensive approach to addressing climate change and promoting sustainable development [19–21]. The UNSDGs and EGD both call for a transformation of the energy system, including a significant increase in the use of renewable energy, energy efficiency, and energy storage. In addition, they advocate for investing in research and innovation, lowering emissions from transportation and buildings, recovering natural carbon sinks, and supporting sustainable urbanisation. To guarantee a fair and equitable transition to a low-carbon economy, both frameworks stress the importance of international collaboration and the elimination of economic and social disparities. Both the UN Sustainable Development Goals (SDGs) and the EGD offer a multi-sectoral and multi-level approach to combating climate change and reaching carbon neutrality [19, 21].

Numerous steps towards carbon neutrality and combating climate change are outlined in both the UN Sustainable Development Goals and the European Green Deal. Some of the most important things a country can do to reach carbon neutrality include [22, 23].

- **Increasing the share of renewable energy in the overall energy mix:** clean energy investments can be made in a variety of areas, such as solar, wind, and hydro.
- **Improving energy efficiency:** The construction, manufacturing, and transportation sectors can all benefit from mandates and guidelines that promote energy efficiency.
- **Electrifying transportation:** The utilisation of public transit systems and the promotion of electric vehicle use are two examples.
- **Implementing a carbon pricing mechanism:** One strategy for doing so is to put a monetary value on carbon emissions in order to encourage their reduction.
- **Investing in carbon capture and storage technology:** One example is funding research into novel technologies that may be used to absorb and store carbon emissions from sources like manufacturing and electricity generation.
- **Protecting and restoring natural carbon sinks:** It's possible to do this through funding projects to increase the amount of carbon stored in forests, wetlands, and other natural ecosystems through reforestation, sustainable agriculture, and other means.
- **Encourage sustainable urbanization:** Emissions from transport and buildings can be mitigated through the promotion of compact and efficient city planning and the funding of smart infrastructure.

- **International cooperation:** The only way to combat the effects of climate change is if countries work together. In order to help poor nations, make the shift to low-carbon economy, it is important to share information, technology, and best practises.

The steps a country takes to attain carbon neutrality will depend on its circumstances, resources, and capabilities, but these are some of the main initiatives that can be highlighted.

4 Green-Hydrogen Research for Net Zero

Green hydrogen is hydrogen generated from non-fossil fuel sources like wind or solar power. Electrolysis (the process of utilising electricity to split water into hydrogen and oxygen) has seen great improvements in efficiency and cost-effectiveness thanks to research into green hydrogen in recent years [24, 25]. Hydrogen production, storage, transportation, fuel cells and combustion engines, end-use applications, grid integration, and industrial applications are just few of the primary topics of green hydrogen research shown in Fig. 3.

Green hydrogen has been produced on a modest scale through several pilot projects and demonstration facilities, with several governments announcing plans to ramp up production to fulfil their net zero targets. While the United States has announced plans to invest $1.7 billion in hydrogen research and development, the European Union has set a target of producing at least 40 GW of renewable hydrogen by 2030 [26].

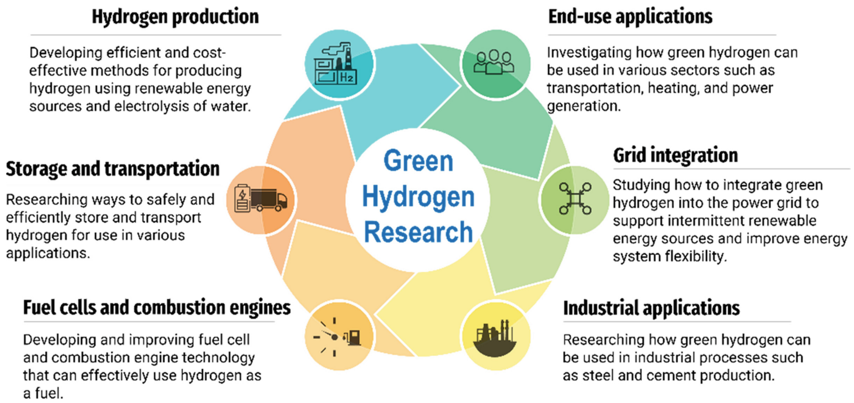

Fig. 3. Research areas of green hydrogen to cater the net zero targets.

Green hydrogen has the potential to play a substantial part in the transition to net zero, especially in the transportation and industrial sectors. Green hydrogen has multiple applications: as a fuel for vehicles like buses and trucks, and as a feedstock for the manufacturing of chemicals and other goods in the industrial sector [27].

Reducing production costs, which are higher than hydrogen produced from fossil fuels, developing hydrogen storage and transport systems, and building hydrogen-powered car pipelines and filling stations are the primary obstacles to achieving widespread production and deployment of green hydrogen. It is expected that research and development activities will continue in the future years to further increase the feasibility and scalability of green hydrogen, which is viewed as a viable technology for achieving net zero emissions. Analysing the legal and policy structures that should be in place to facilitate the introduction of green hydrogen [26].

Green hydrogen generation and deployment are challenging. To become cost competitive, green hydrogen needs technology advances and economies of scale. Lack of green hydrogen production, storage, and delivery infrastructure is another obstacle. Infrastructure expansion requires significant investments and stakeholder collaboration. Due to renewables' intermittent nature, integrating them to supply green hydrogen is difficult. Research, public-private partnerships, supportive policies and incentives, international collaboration, and large-scale demonstration projects are needed to overcome these problems [26].

Optimising electrolysis efficiency, developing new materials, and providing a stable policy framework with long-term aims and incentives are necessary to maximise green hydrogen's potential in transportation and industry. Public-private collaborations can give resources and skills, while international collaboration can help standardise information. Large-scale projects will prove green hydrogen's viability and boost investment. Green hydrogen can decarbonize transportation and industry and accelerate the transition to a sustainable energy future by tackling these difficulties and applying appropriate measures [27].

5 Digital Circular Economy for Net Zero

The digital circular economy (DCE) is a strategy for developing and making use of digital technology that seeks to minimise damage to the natural world while maximising opportunities for long-term, sustainable growth. By reusing, repairing, refurbishing, and recycling digital products, services, and infrastructures, it hopes to reduce resource consumption and waste [28].

Since the digital sector accounts for about 4% of global greenhouse gas emissions, the DCE can play a significant role in cutting down on that number. The DCE can also support the transition to a low-carbon economy by enabling the efficient use of resources, the optimization of energy consumption, and the development of low-carbon digital products and services [29].

By enhancing the traceability and transparency of products and sustainable materials, digital technologies can pave the way for circular business models like product-as-a-service and circular procurement that are key to the circular economy. Through the use of sensors and Internet of Things (IoT) devices to monitor the performance and condition of products and assets, digital twinning enables the efficient use of resources by simulating and optimising production processes. By supporting the circular design of digital products, services, and infrastructures, which can extend their lifetimes and reduce the need for new resources [30].

Following steps should be taken to promote circular economy.

- Statutory Reforms
- Syncing Laws with Implementation Strategies

- R&D Investments
- Technology Driven Recycling

Therefore, the digital circular economy can play a significant role in achieving net zero emissions by reducing the environmental impact of the digital sector and enabling the transition to a low-carbon economy.

To ensure the safe and sustainable development of nanotechnology, key measures include robust risk assessment methodologies, a comprehensive regulatory framework, sharing safety data, conducting lifecycle assessments, promoting public awareness and education, fostering international cooperation, addressing ethical considerations, and allocating funding for research. These measures aim to mitigate risks, set guidelines for responsible use, and safeguard human health, the environment, and societal well-being throughout the lifecycle of nanomaterials.

6 Nanotechnology Net Zero Roadmap and Challenges

Figure 4 shows a nanotechnology net zero roadmap. Research and development should identify and develop nanotechnology-based solutions to reduce greenhouse gas emissions and improve energy efficiency. Sustainable materials and manufacturing should develop and implement high performance materials to improve the performance and cost-effectiveness of renewable energy, energy storage, and carbon capture and storage systems. To reduce greenhouse gas emissions and improve energy efficiency, nanotechnology-based solutions should be implemented and deployed in transportation, buildings, and industry [31, 32].

Monitoring and evaluation should assess nanotechnology-based solutions' impact on net zero goals and identify areas for improvement and optimization. Partnerships and collaborations between academia, industry, and government should accelerate the development, implementation, and deployment of nanotechnology-based net zero solutions. Education and outreach should inform stakeholders, including the public and policymakers, about nanotechnology's potential to achieve net zero goals and the importance of investing in its development and deployment [32, 33].

Fig. 4. A roadmap for nanotechnology to achieve net zero goals.

Establishing collaborative platforms, financing methods, and joint research goals can encourage partnerships between academia, industry, and government in nanotechnology. There are several advantages to working together. In the first place, they facilitate the implementation of theoretical findings by coordinating academic knowledge with commercial and public interests. Second, collaborations encourage information sharing and new perspectives, which in turn spurs revolutionary developments in nanotechnology. These collaborations speed up the creation of new technologies, tackle difficult problems, and propel the responsible use of nanotechnology solutions towards the achievement of net-zero targets and sustainable development [34, 35].

Guidelines and regulations should be developed to ensure the safe and sustainable deployment of nanotechnology-based solutions, after assessing and mitigating the safety and environmental hazards of nanotechnology in various applications [34].

Nanotechnology has a great potential to achieve net zero goals but there are also potential risks and unintended consequences associated with the widespread implementation of nanotechnology. Engineered nanoparticles may provide significant environmental and health risks if released in big amounts. Nanomaterials can infiltrate cells and interact with biological systems in unknown ways, causing oxidative stress. Nanotechnology's long-term effects on ecosystems and societies, especially in developing nations, are another risk. Nanotechnologies may worsen social and economic inequality, and underprivileged communities may be most affected by nanomaterials' environmental consequences [9, 12].

7 Conclusions

Nanotechnology is a promising new field of study that may play a crucial role in getting us to net zero by facilitating the development of methods to cut down on carbon emissions and boost energy productivity. Nanotechnology improves building materials with self-cleaning surfaces, energy-efficient windows, stronger and lighter materials, fire-resistance, and smart capabilities. Renewable energy technologies, energy storage systems, and carbon capture and storage systems are all examples of emerging worldwide trends in nanotechnology. Building partnerships and collaborations between academia, industry, and government to speed up the development, implementation, and deployment of nanotechnology-based solutions for achieving net zero goals and assessing and mitigating the safety and environmental risks associated with their use, are also receiving increased attention. Nanotechnology has the potential to aid in the achievement of net zero energy goals, and there is a rising movement to raise public and governmental awareness of this fact, as well as the need of investing in the technology's research, development, and eventual implementation. Thus, nanotechnology cannot be the only solution to climate change, though, it can be a significant factor in bringing us closer to our zero-carbon objectives. Achieving net zero objectives would necessitate a multifaceted approach and cooperation amongst several sectors and industries. Advanced nanomaterials with improved efficiency and performance, scalable manufacturing methods, integration with emerging technologies, environmental and safety concerns, and interdisciplinary collaborations should be prioritised to advance nanotechnology's contribution to net zero emissions. Nanotechnology can accelerate net zero emissions by advancing clean energy generation, storage, and conversion, energy-efficient materials and devices, and sustainable practices.

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