sustainable chemistry

MDPI

Review

The Multifaceted Perspective on the Role of Green Synthesis of Nanoparticles in Promoting a Sustainable Green Economy

Manish Kumar Sah [1], Biraj Shah Thakuri [1], Jyoti Pant [2], Ramesh L. Gardas [3,*] and Ajaya Bhattarai [1,3,*]

1 Department of Chemistry, Mahendra Morang Adarsh Multiple Campus, Tribhuvan University, Biratnagar 56613, Nepal; manish.sah820226@gmail.com (M.K.S.); birajthhakuri7@gmail.com (B.S.T.)
2 Central Department of Chemistry, Tribhuvan University, Kirtipur 44613, Nepal; pantjyoti248@gmail.com
3 Department of Chemistry, Indian Institute of Technology Madras, Chennai 600036, India
* Correspondence: gardas@iitm.ac.in (R.L.G.); ajaya.bhattarai@mmamc.tu.edu.np (A.B.); Tel.: +977-9842-077-434 (A.B.)

Abstract: The current economic development paradigm, which is based on steadily rising resource consumption and pollution emissions, is no longer viable in a world with limited resources and ecological capacity. The "green economy" idea has presented this context with a chance to alter how society handles the interplay between the environmental and economic spheres. The related concept of "green nanotechnology" aims to use nano-innovations within the fields of materials science and engineering to generate products and processes that are economically and ecologically sustainable, enabling society to establish and preserve a green economy. Many different economic sectors are anticipated to be impacted by these applications, including those related to corrosion inhibitor nanofertilizers, nanoremediation, biodegradation, heavy metal detection, biofuel, insecticides and pesticides, and catalytic CO_2 reduction. These innovations might make it possible to use non-traditional water sources safely and to create construction materials that are enabled by nanotechnology, improving living and ecological conditions. Therefore, our aim is to highlight how nanotechnology is being used in the green economy and to present promises for nano-applications in this domain. In the end, it emphasizes how critical it is to attain a truly sustainable advancement in nanotechnology.

Keywords: biofuel; insecticides; pesticides; catalytic reduction of CO_2; green economy; sustainability; nanoparticles; corrosion inhibitor; nanofertilizer; heavy metal detection

Citation: Sah, M.K.; Thakuri, B.S.; Pant, J.; Gardas, R.L.; Bhattarai, A. The Multifaceted Perspective on the Role of Green Synthesis of Nanoparticles in Promoting a Sustainable Green Economy. *Sustain. Chem.* **2024**, *5*, 40–59. https://doi.org/10.3390/suschem5020004

Academic Editor: Konstantinos S. Triantafyllidis

Received: 14 January 2024
Revised: 15 March 2024
Accepted: 20 March 2024
Published: 25 March 2024

1. Introduction

Many factors have contributed to the widespread acceptance of the "green economy" concept in policy discussions. These include the ongoing global economic crisis, the projected increase in global energy demand of more than one-third between 2010 and 2035, price hikes for commodities, and the urgent need to address global issues about energy, the environment, and health. The term "green economy", which mostly relates to the ideas of sustainable development, was first used by a group of well-known environmental economists in a revolutionary 1989 assessment for the federal government of the United Kingdom [1–3]. The most widely recognized and reliable definition of a "green economy" comes from the United Nations Environment Programme, which states that one is "a green economy if it leads to enhanced human well-being and social equity while substantially decreasing environmental risks and environmental shortages". It is socially inclusive, low-carbon, and resource-efficient [4].

A collection of concepts, objectives, and practices collectively referred to as the "green economy" include (i) advocating for justice and equity for all generations; (ii) upholding sustainable development principles; (iii) applying caution about the environment and social effect; (iv) appreciating natural and social capital through techniques such as whole-life expenses, internalizing external costs, and enhancing governance; (v) utilizing resources wisely and effectively; and (vi) aligning with previously present macroeconomic objectives by abolishing poverty, fostering green jobs, and enhancing competitiveness as well as development in significant industries [3–7].

It is widely acknowledged that nanoparticles play a key role in easing the shift to a green economy, which is defined by environmentally friendly and sustainable technologies. This recognition is a result of their unique qualities, which make it possible to use resources wisely and effectively. These materials have tremendous prospects for the creation of energy-efficient and commercially viable solutions at the nanoscale, which is consistent with the broad goals of the green economy [8].

The application of nanoparticles in the green economy has the potential to revolutionize various industries and promote sustainability. To ensure the success of nanoparticle applications in the green economy, careful consideration of these factors is essential to strike a balance between innovation and responsible implementation [9].

This study examines the opportunities and real-world challenges that nano-applications offer for addressing the principles of a green economy. There are examples given of how nano-applications could help with social and environmental issues. Green synthesis produces highly efficient nanoparticles without affecting the environment. The goal of this review article is to promote the use of regional botanical items for the synthesis of nanoparticles and their application for the control of environmental issues that harm both human health and the environment. Such a problem is faced worldwide, whether in developed countries, developing countries, or underdeveloped countries. This review supports the pathway to prepare nanoparticles and use them for mitigation in ecofriendly means, which is also a visionary action for sustainable development. This review is also concerned with the green synthesis of nanoparticles and their mitigation approach toward environmental problems, etc. Moreover, the study also focuses on the unique approach of green synthesis of nanoparticles, which are highly efficient, responsive to external stimuli, and cheap. The transformative potential of green nanotechnology across various sectors such as biofuel, CO_2 reduction, detection of heavy metals, and many more is demonstrated graphically in Figure 1.

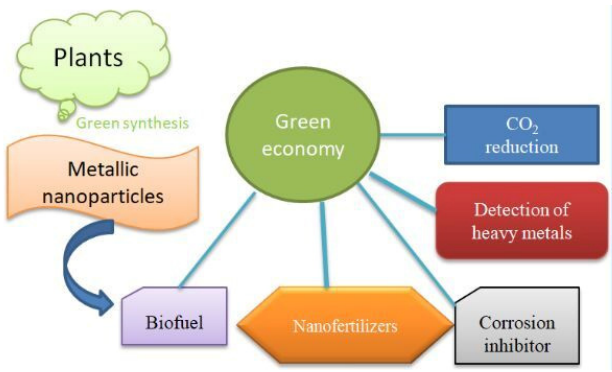

Figure 1. Exploring the transformative potential of green nanotechnology across various sectors.

2. Green Synthesis

The environmentally friendly synthesis of nanoparticles is essential for the development of a green economy because it provides viable substitutes for conventional synthesis techniques. Green synthesis is the process of recycling biological and agricultural waste to minimize environmental effects while fostering resource efficiency and the circular economy. The resultant nanoparticles frequently show improved biocompatibility, which qualifies them for use in industry, agriculture, and medicine. All things considered, the green synthesis of nanoparticles addresses environmental issues, encourages innovation and supports responsible resource management, all of which lead to a more robust and sustainable economy [10,11].

A broad area of study encompasses multiple nanotechnology applications. There is now a trend to employ NPs for environmental purposes. Metallic nanoparticles are one of the many kinds of nanoparticles (NPs) employed in environmental applications. Plant-assisted synthesis of NPs is more affordable, ecologically benign, and commercially feasible than chemical and physical procedures [12,13]. Most often, in green synthesis, plant components are used as reducing and capping agents. Leaf, bark, fruit, and flower extracts have been used to make metallic nanoparticles (NPs) of a variety of sizes and shapes [14]. Particles made via green synthesis are not the same as particles generated via physicochemical methods. Metal or metal oxide nanoparticles were created by employing the bottom-up method. The green synthesis comprised the use of a costly chemical-reducing agent with a natural extract like the leaves from plants, crops or parts of fruits. There is enormous potential for the creation of NPs in biological beings. The reduction in metal precursors to respective NPs using biological sources is an environmentally friendly process. In general, the synthesis of NPs can be performed either "Top Down" or "Bottom Up" as in Figure 2, which illustrates a potential biological process for creating NPs [15]. Table 1 describes the use of plant-based green synthesis nanoparticles.

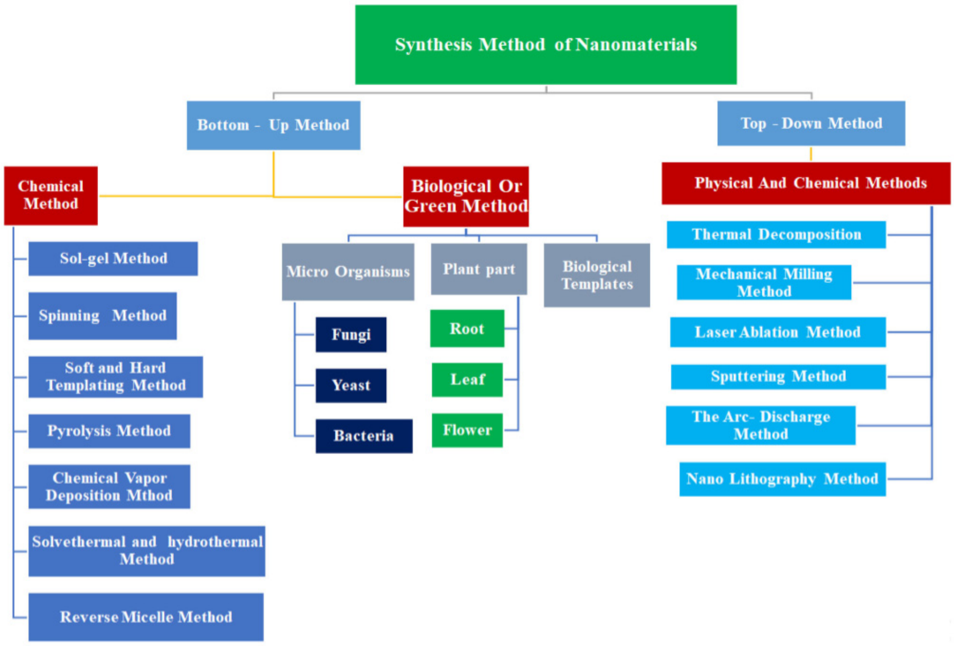

Figure 2. Scheme for green synthesis of NPs.

Table 1. Nanoparticles from plants and their applications.

Plant	Nanoparticles	Applications	Reference
Ficuscarica	Fe_3O_4	Antioxidant	[16]
Azadirachtaindica	CuO	Anticancer	[16]
Peltophorumpterocarpum	Fe_3O_4	Degradation of rhodomine	[17]
Terminalia chebula	Fe_3O_4	Degradation of MB	[17]
Punicagranatum	ZnO	Antibacterial	[18]
Lactucaserriols	NiO	Dye degradation	[19]
Vitisrotundifolia	CoO	Acid blue dye degradation	[20]
Ziziphus spina-christi	ZnO-SeO	Antimicrobial/antioxidant activity	[21]
Seriphidiumoliverianum	CuO	Photocatalytic dye degradation from water	[22]
Punicagranatum	Ag_2O	Antibiotic removal from wastewater	[23]
Jacaranda mimosaefolia	Cu	Corrosion inhibition	[24]
Scallion's peel	ZnO	Nanofertilizer	[25]
FicusBenjamina	TiO_2	Heavy metal detection	[26]
watermelon	CaO	The catalyst for biofuel production	[27]
Cola nitida	FeO	Absorption of MB/MO dye from wastewater	[28]

3. Applications

The current economic model is no longer viable in a society with finite resources and ecological capability since it depends on increasing pollution and resource consumption. The idea of the "green economy" presents an opportunity to redefine the environment–economic interface. Moreover, the application areas of nanoparticles include taking higher-resolution pictures, making nano-detectors for ecological contamination, and providing a high quantity of optoelectronics strategies in solar energy application processes, catalysts, and many more. Additionally, innovative nanostructures of silica efficiently eliminate contaminants [29–31]. In the past, researchers engaged in developing carbon- or mineral-based nanoparticles for effective services to serve mankind [32–35]. This review is concerned with the green synthesis of nanoparticles and their mitigation approach towards the environmental problem via biodiesel, heavy metal detection, catalytic conversion of CO_2, etc. Moreover, the study focuses on the unique approach of the green synthesis of nanoparticles, which are highly efficient, responsive to external stimuli, and cheap, as shown in Figure 3. The green synthesis produces highly efficient nanoparticles without affecting the environment.

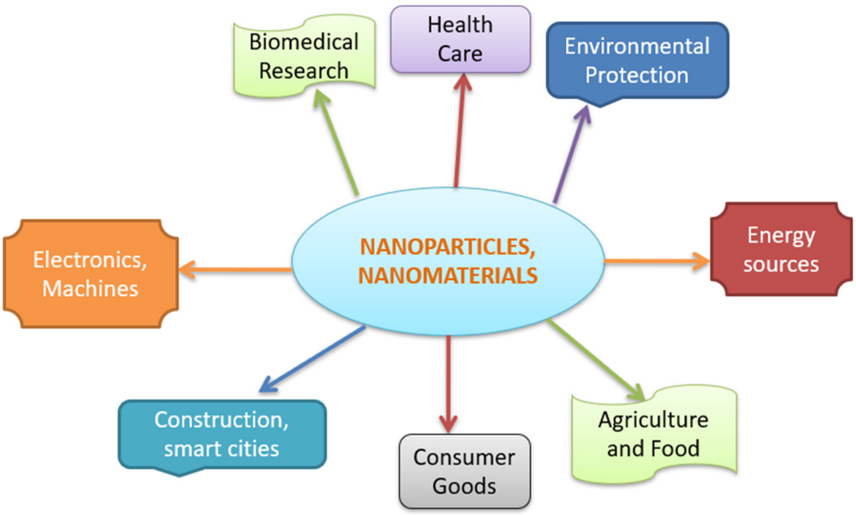

Figure 3. Multiple application of nanoparticles.

"Green nanotechnology" affects industries, including biofuel, nanofertilizers, nanoremediation, and more by employing materials science's nanotechnologies to create economically and ecologically sound goods. Our goals are to address issues, particularly those related to worker health and safety, to emphasize the role that nanotechnology plays in promoting a green economy, and to underscore the necessity of sustainable advancements in nanotechnology.

Green-synthesized nanoparticles are essential to nature and have the following extensive applications.

3.1. Corrosion Inhibitor

The National Association of Corrosion Engineers (NACE International) reported in 2016 that the yearly cost of worldwide corrosion losses is USD 2.5 trillion, or 3.4% of the world GDP in 2013 [36,37]. The research shows that the corrosion losses in the world's leading economies differ, with the US suffering 2.7% and China 4.2%. The effective use of currently available corrosion management techniques might potentially cut these losses by 15–35%, or USD 375–875 trillion annually on a worldwide scale [38]. This emphasizes the need for strong corrosion prevention technologies that are affordable and long lasting. In addition, there is a need for ongoing research into novel and long-lasting anticorrosion solutions to deal with this widespread problem that affects many different sectors and businesses globally.

The high volume-to-surface ratio of nanoparticles has led to a recent increase in the application of nanotechnology in corrosion inhibition. Nanoparticle coatings can be used to reduce corrosion, a costly and harmful natural occurrence, by functioning as barriers to limit the rate of corrosion. Despite their effectiveness, synthetic corrosion inhibitors are becoming less common because of environmental regulations and toxicological issues [36,37]. Promising substitutes include plant extracts like Chelidonium majus that naturally reduce rusting [38]. These environmentally friendly methods, which make use of plant extracts and phytochemicals, show promise in lowering dependency on hazardous chemicals, which represents a major breakthrough in corrosion prevention [39–47].

Due to its ability to increase the sustainability and efficiency of corrosion protection techniques, nanoparticles' involvement in corrosion inhibition significantly advances the green economy. As corrosion inhibitors, nanoparticles provide metallic surfaces with durable protection that lowers maintenance costs and increases infrastructure longevity. Environmentally friendly and economical methods are frequently used in the application of these nanomaterials, which reduces the ecological impact of corrosion prevention and conserves resources. The approach of its application is presented in Figure 4 [48–50].

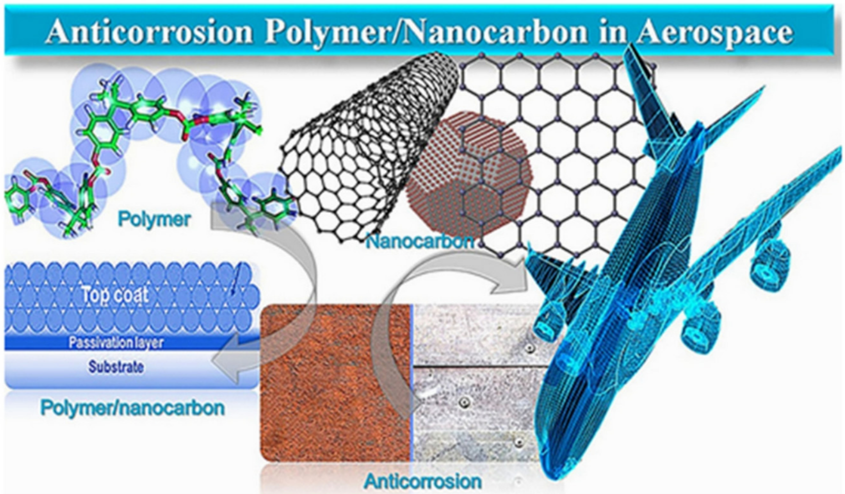

Figure 4. Multiple applications of nanoparticles.

By depositing surfactant $C_{16}H_{33}N + (CH_3)3[CeCl_3Br] -$ (CTACe)-modified silica nanoparticles, a metallic material was endowed with a good resistance to corrosion [27]. Since they are effective in preventing and managing the surface deterioration of metals caused by various corrosive substances, they are regarded as the most significant corrosion inhibitors [51–53]. Table 2 lists the nanoparticles that were isolated from the plant with their corresponding efficacy values.

Table 2. Nanoparticles for green corrosion inhibitor.

Nanoparticle	Plant	Effect	Efficacy	Reference
Glycogen NP	Biogenic sources	Controlled the corrosion of zinc in sulfamic acid (NH_2SO_3H)	92% for 0.02 gL^{-1}	[23]
CuO	*Moringa oleifera* leaf extract	Improved overall anticorrosive activity	56%	[23]
Manganese oxide	Rose petal (RP) and lotus petal (LP)	Overall anticorrosion behaviour of mild steel increased	72.63%	[23]
Ag	*Citrus reticulata* peels extract	Inhibited steel corrosion from HCl	93.9% at 303 K and 90.3% at 333 K	[54]
Ag	Palm oil leaf extracts	A protective film formed, which protected the steel from acid attack	94.1%	[55]

Table 2. *Cont.*

Nanoparticle	Plant	Effect	Efficacy	Reference
Ag nanocomposite	Red onion peels	A surface protection layer formed against corrosion	86%	[56]
Cellulose nanocrystal	Organic product	Protected AISI360-steel from corrosion in petroleum manufacturing	85.3% at 300 mgL^{-1}	[57]
CuO/melamine/cellulose nanocrystals nanocomposite	Organic product	Protected AISI360-steel from corrosion in petroleum manufacturing	96.8% at 300 mgL^{-1}	[58]
NiO/melamine/cellulose nanocrystals nanocomposite	Organic product	Protected AISI360 steel from corrosion in petroleum manufacturing	98.3% at 300 mgL^{-1}	[59]

3.2. Nanofertilizers

The production of mineral fertilizers is dominated by the US, China, India, and the EU, with nitrogen accounting for 60% of the total and phosphorus and potassium, making up 20% apiece [60]. The conflict between Russia and Ukraine will cause natural gas prices to rise in Europe in 2022, which will have a negative effect on energy-intensive industries like fertilizers. Since natural gas is essential to the production of fertilizers, European producers are changing their methods, which may result in a halt or reduction in production. Gas price increases reduced Europe's supply of nitrogen fertilizer by 25% by September 2022 [61–63]. Even though the COVID-19 pandemic, climate change, and conflicts at first helped to reduce world hunger, undernourishment rose and now affects 10% of the world's population (828 million) in 2021, up from 8% (678 million) in 2019. Creative thinking is required to meet the UN's aim of zero hunger [64–66].

Through the optimization of agricultural output and resource utilization, nanofertilizers are essential to the advancement of the green economy. By precisely delivering nutrients, nanofertilizers increase crop yields and foster economic efficiency in the agriculture industry. Farmers save money because of the reduced need for fertilizers due to the regulated release of nutrients. Moreover, nanofertilizers help to ensure the sustainability of agricultural operations and their long-term economic viability by reducing environmental consequences, including pollution and nutrient runoff. In addition to providing financial benefits to farmers, the technology's ability to enhance soil health and nutrient use efficiency positions agriculture as a more resilient and environmentally conscious component of the broader green economy. The broad use of nanofertilizers holds promise for a more environmentally and economically sustainable agricultural future as they continue to provide benefits through higher yields, resource conservation, and less environmental externalities [67–69].

The use of zinc oxide nanoparticles as a foliar fertilizer has been shown in several studies to enhance the agro-morphological characteristics, photosynthesis, and yields of wheat plants [70] and common bean plants. Tomato plants' traits and yield are enhanced by carbon nanoparticles [71]. Zinc oxide nanoparticles are a more effective way to support wheat growth and germination than zinc sulphur dioxide. Additionally, at larger dosages, they demonstrated in the literature that zinc sulphur dioxide posed a greater risk than ZnO NPs [72]. The common bean that is harvested from the ZnO NP-treated plant affects the lipid parameters and the liver and renal functions of the rats that consume it [13]. Many plants, like squash, require the three nutrients iron, manganese, and zinc to flourish [73,74]. Furthermore, as observed by Kaur et al., the application of Mn nano-oxide greatly decreased the yield of fruit squash (kg/plant and tons/hectare), particularly when coupled with the application of Fe nano-oxide. It was also mentioned that the fruits of squash plants sprayed with Fe oxide nanoparticles had higher concentrations of energy, proteins, lipids, and organic matter [13].

Moreover, NFs may raise plants' defence mechanisms, lengthen stress resistance, and improve nutrient absorption and output by maintaining the accessibility of nutrients in the rhizosphere. Due to their better suitability for promoting plant development, they can potentially replace synthetic fertilizers and provide a new route for sustainable and healthy agriculture [75]. They reduce external pressures and improve tolerance to unfavourable environmental conditions for plants. Recent nano-technological developments have been filling the gaps between agriculture and technology and have craved a sustainable plan for solving the global food crisis [76]. In light of this, nanoparticles are quickly becoming a cutting-edge agro-technology for agro-improvement. Surprisingly, they give crop plants the ability to resist stress, as described in Figure 5 [77]. Additional nanofertilizers have been studied with respective plants and are presented in Table 3.

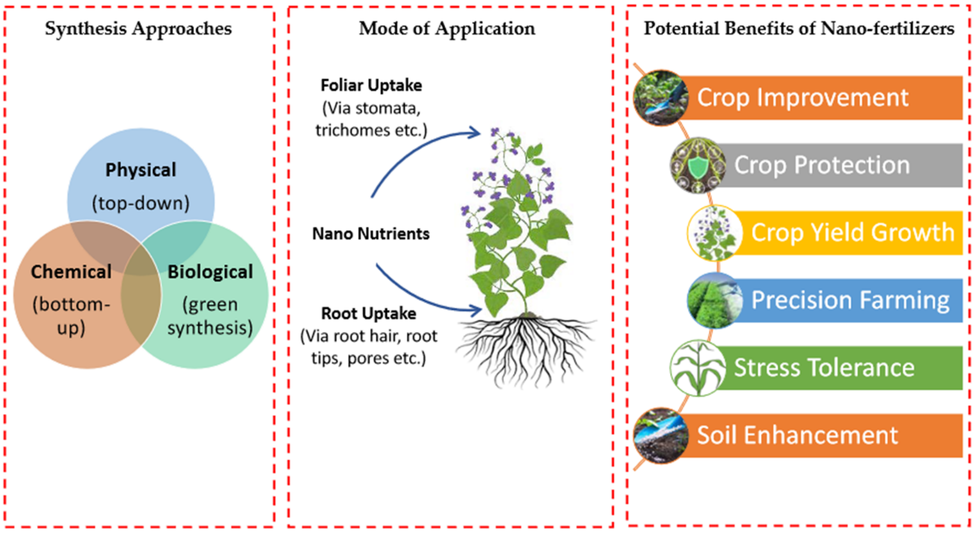

Figure 5. Multiple utilities of NPs [78].

Table 3. Nanoparticles used as nanofertilizers.

Nanoparticle	Plant Affected	Effect	Reference
Hydroxylapatite ($Ca_5(PO_4)_3OH$)	Soybean (*Glycine max*)	Increase of 33% growth rate and 20% seed yield	[79]
AgNPs	Red ginseng shoot	Ginsenoside content increased	[80]
TiO_2	Aged spinach seeds	Increased germination rate due to increase in nitrogen assimilation	[81]
Iron oxide	Soybean	48% increase in grain yield	[82]
Ag	*Fusarium solani*	Reduced fungal infection	[83]
C nanoparticle	*Phaseolus vulgaris* L.	Improved the quality and constituents of leaves and seeds	[84]
K^+, Fe, tryptophan, urea, amino acids	Tomato, fenugreek	Increased germination percentage of tomato from 14% to 97% and fenugreek from 25% to 93.14%	[85]
Nano-NPK	*Capsicum annuum* leaves	Resulted in better fruit quality and increased the yield	[85]

3.3. Heavy Metal Detection

By solving environmental issues and fostering economic sustainability, the use of nanoparticles in heavy metal detection is crucial to the growth of the green economy. When used with state-of-the-art sensing technologies, nanoparticles improve the accuracy and efficacy of heavy metal detection techniques, allowing for the early detection of pollution in soil, water, and air. This reduces the financial burden of environmental cleanup and medical costs while also protecting human health and ecosystems [86]. Industries are adopting detecting systems based on nanoparticles in compliance with strict environmental rules, which lowers the possibility of legal repercussions and increases corporate accountability. Businesses that invest in and use these technologies not only help to create a cleaner and healthier environment, but also boost economic growth by creating and distributing novel solutions that support a green economy that is more robust and sustainable [87,88].

The primary heavy metals that are environmentally hazardous in recent research are $Pb^{2+,}$ Cr^{3+}, Hg^{2+}, As^{3+}, and Cu^{2+}. As a result, several attempts have been undertaken to measure and detect heavy metals using analytical techniques [89]. However, current technology is still needed for the sensitive and user-friendly detection of heavy metals. In response to this, nanotechnology was created. These nanotechnologies were demonstrated to be extremely sensitive, selective, and fast-acting, which improved the efficacy of analytical equipment [90]. For several reasons, including their low detection limit, high linear range, and ease of system integration, nano-based sensors are an effective tool for on-the-spot identification or on-field recognition. The benefits of using ways based on nanotechnology gave them a new idea for combining these technologies into portable devices that can be used anywhere and at any time, as Figure 6 illustrates [91]. Table 4 also contains a tabulation of the nanoparticles that were employed to detect heavy metals.

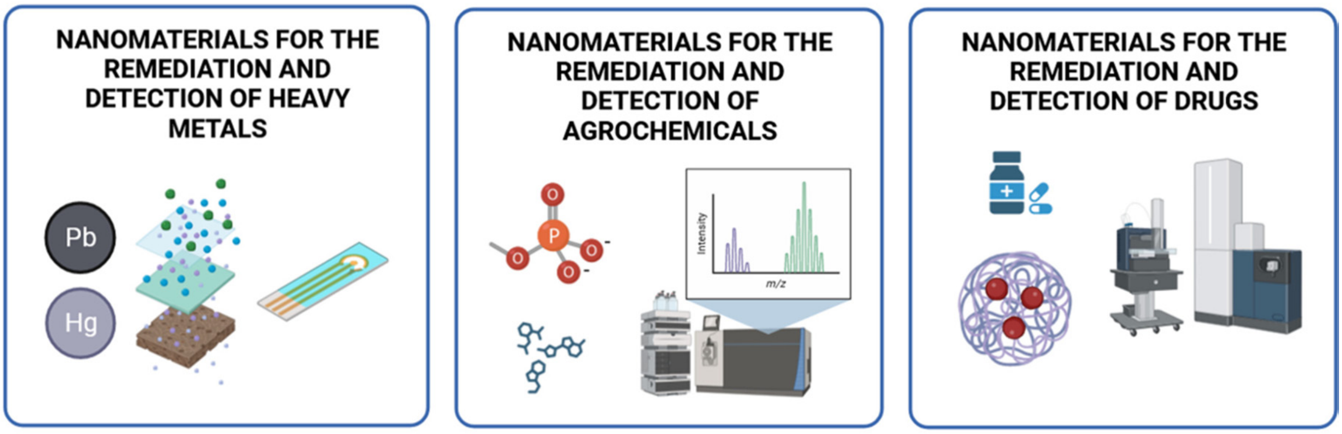

Figure 6. Nanoparticles' intervention for heavy metal detection [92].

Table 4. Nanoparticles used for heavy metal detection.

Nanoparticles	Heavy Metal Detected	Limit of Detection	Reference
Multiwalled carbon nanotube	Zn (II)	0.3 μgL^{-1}	[93]
Multiwalled carbon nanotube	Pb (II)	0.07 μgL^{-1}	[93]
Multiwalled carbon nanotube	Cd (II)	0.1 μgL^{-1}	[93]
CNT/Pt	As (III)	-	[94]
Au-decorated Te hybrids	As (III)	0.0026 ppb	[95]
AuNP	Hg (II)	-	[96]
AuNP	As	0.01 µM	[97]
Graphene	Cd (II)	10^{-7} M	[98]
Graphene oxide	Cd (II)	0.1–1.5 µM	[99]
Graphene oxide	Hg (II)	2.5×10^{-8} M	[100]
AuNP	Cr	0.01 µM	[100]
Carbon nanofibers	Bi (III)	16.8 μgL^{-1}	[101]
Carbon nanofibers	In (III)	3 μgL^{-1}	[101]

3.4. Biofuel

Out of all the basic energy sources, fossil fuels account for 80% of the world's energy consumption [102]. Estimates indicate that bioenergy will become more significant, particularly in contemporary bioenergy applications, with a predicted increase to 145 EJ by 2060 [103]. For large-scale energy production, a variety of feedstocks, including wood, plants, and crops high in starch or oleaginous seeds, are suggested, including algae, crops, and lignocellulosic biomass [104]. In order to generate electricity, current power systems must first go through lengthy transmission and transformation operations before using the energy for end consumption [105].

Fossil fuels are the main energy source, but they also contribute to climate change, which is dangerous [106,107]. The world's population is approaching 8 billion, and as technology develops, so does the demand for energy, with fossil fuels continuing to be the most popular source [108,109]. In order to comply with the Paris Agreement, the European Commission's "Fit for 55" plan seeks to achieve climate neutrality by 2050 and a 55% reduction in net emissions by 2030 [110].

One of the keystones for advancing the green economy is the use of nanoparticles in the manufacturing of biofuel. When used as additives or catalysts, nanoparticles improve the productivity of biofuel synthesis processes, leading to higher yields and lower production costs. They play a key role in increasing the production of sustainable fuels because of their capacity to enhance reaction conditions and the overall effectiveness of biofuel production technologies. The application of nanoparticles makes it easier to create economical and ecologically beneficial processes for producing biofuels, which draws capital and promotes economic expansion in the renewable energy industry. A more effective and financially feasible route to sustainable energy is made possible by industries' growing adoption of nanoparticle technology for the manufacturing of biofuels, and this is reflected in Figure 7 [110–112].

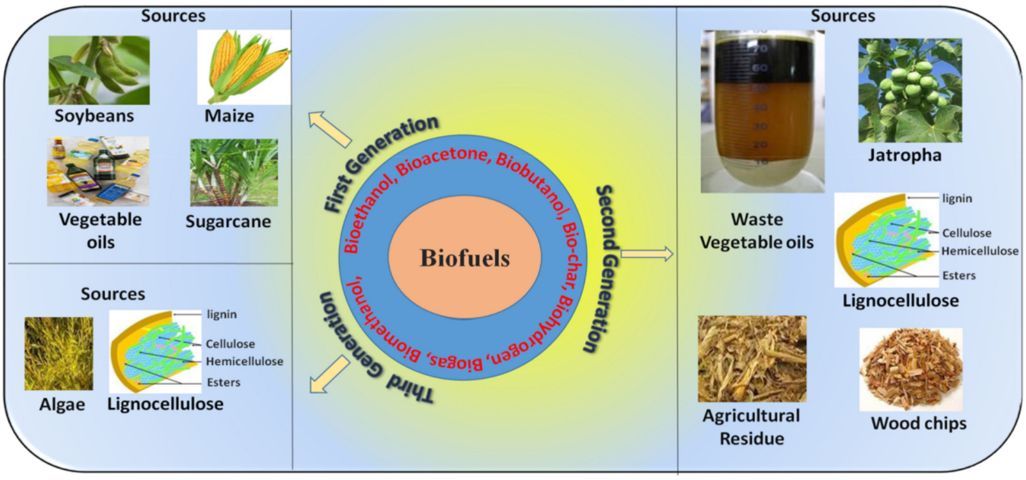

Figure 7. Utilizing catalysts for the production of biofuel [112].

Utilizing green copper oxide nanoparticles, a study enhanced the transesterification of citrus medica-generated biodiesel in the core composite design. This green biodiesel that was manufactured adhered to international standards for properties like methyl ester. The characteristics of the biodiesel generated by this procedure demonstrate that it falls within the range of ASTM criteria. Green ZnO nanoparticles produced from banana corm extract showed significant performance in the production of biodiesel from waste fish lipids, with an ideal yield of 2.5% and over 90% transesterification efficiency [113]. The use of nanoparticles as catalysts for the production of biofuels are given in Table 5.

Table 5. Nanoparticles used as the catalyst for biofuel.

Nanoparticles	Effect	Reference
Carbon nanotubes	Their use in biosensors and microbial fuel cell fabrication as well as a catalyst in biofuel production raise the overall concentration of enzymes in biofuel generation, as well as help in enzyme mobilization	[114,115]
Aniline incorporated with Fe_3O_4-NH_2 and reduced graphene oxide nanocomposites	Enhances the process of bio-electrocatalysis of glucose oxidase	[116]
Magnetic nanoferrites doped with calcium	Raises biodiesel production yield	[117]
MnO_2 with sugarcane leaf	Increases bioethanol synthesis	[118]
Nano zero-valent iron (nZVI) and Fe_2O_3	Improves the production of biogas like methane	[119]
CeO_2	Improves the production of biogas	[120]
Pt and silica	Raises methane production yield	[121]
Ni and silica	Raises methane production yield	[121]
Co and silica	Raises methane production yield	[121]
Fe and silica	Raises methane production yield	[121]

3.5. Catalytic Reduction of CO_2

With the goal of achieving zero domestic net emissions by 2050, the government formed the Presidential Carbon Neutrality Committee in 2021 and unveiled the ambitious Carbon Neutrality Scenario 2050. The national greenhouse gas reduction target (NDC) was suggested to be increased by 40% by 2030 in comparison to 2018 levels by the committee [122]. As opposed to large industrialized nations like the UK, France, and Germany, which have been progressively lowering their emissions since the early 1990s, the predicted implementation period for carbon neutrality is between 50 and 60 years.

A third of the workforce in Asia work in climate-sensitive industries like agriculture and fisheries, making the region, which is home to roughly 70% of the world's population, subject to immediate risks from rising sea levels. Asia's developing countries may see a 24% GDP decline by 2100 if current warming trends continue, and the region's proportion of global greenhouse gas emissions will practically double from 22% in 1990 to almost 50% in 2021 [123].

When it comes to catalytic CO_2 reduction, nanoparticles are revolutionary and greatly advance the green economy. These small catalysts, which are frequently made of sustainable materials, improve the effectiveness of CO_2 conversion processes and open up new economic opportunities by producing useful chemicals and fuels. Their distinctive characteristics and large surface area improve catalytic efficacy, maximizing reaction rates and lowering energy inputs. The commercial feasibility of CO_2 reduction technologies can be enhanced by the application of nanoparticles, which can result in scalable and affordable catalytic systems [124–126].

The environmentally benign photocatalytic reduction of CO_2 to CH_3OH is achieved by the use of nanoporous CeO_2, while sunlight is employed to initiate exothermic combustion, ensure uniform heating, and create vacancies in CeO_2. The homogeneous distribution of heat energy made possible by the nanosize can raise CeO_2's reduction efficiency [127]. The triple-functional precursor NH_3BH_3, which has a narrow band that enhances light energy harvesting and electron transfers via the catalyst for surface adoption of CO_2 in reduction, was used to synthesize the B, N co-doped TiO_2 nanosheets [128]. Table 6 tabulates the nanoparticles involved in CO_2 removal while the schematic diagram is shown in Figure 8.

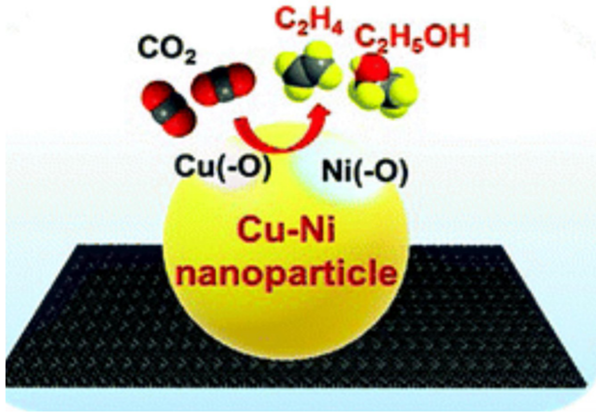

Figure 8. Usability of nanoparticle [129].

Table 6. Nanoparticles that serve to reduce CO_2.

Nanoparticle	Treated along with	Period of Experiment	Temperature	Reference
CoNP-treated cocoa shell	Cocoa shell and 3-aminopropyltriethoxysilane		25 °C	[130]
Magnetite nanocapsule nanocomposites	Polyaniline	90 min	28 °C	[130]
Porous silica nanoparticles	Polyethyleneimine	30 min	75 °C	[131]
La and Ce	Zeolite	-	0, 30, 60 °C	[131]
CaO	Egg shell waste	23 min	700–900 °C	[132]
MgO	Graphene oxide	-	60–120 °C	[132]

3.6. Insecticides and Pesticides

Pesticide sales in the EU increased by 2.7% in 2021 to 355,175 tons, with agriculture being the primary user of these chemicals [133]. The Kyoto Protocol set off worldwide efforts to limit greenhouse gas (GHG) emissions in order to limit temperature increases to less than 2 °C. However, despite the fact that it was meant to end in 2012, many nations' inadequate efforts to reduce carbon emissions caused it to continue longer [134,135].

Due to their revolutionary effect on agricultural operations, nanoparticles in herbicides and insecticides represent a significant step toward the advancement of the green economy. Pesticides and insecticides using nanoparticle-based formulations have a more focused and regulated delivery system, which boosts effectiveness while reducing environmental impact. The implementation of solutions based on nanoparticles improves resource efficiency and reduces the financial and ecological expenses linked to conventional pesticides. As a result of industry investments in and use of these cutting-edge technologies, the objectives of a green economy are advanced and a more environmentally conscious and sustainable agricultural sector is fostered, and economic growth is stimulated through the development and commercialization of cutting-edge environmentally friendly pest control solutions [136–138].

The usage of nanoparticles as insecticides in agriculture has increased recently. It is also being used as an inexpensive sensing tool, which has to be studied for better farming practices and higher yields [127]. Ulrichs et al. claim that NPs have a large surface area that affects lepidopteran insects in less than a day, which is necessary for human use [128]. Table 7 presents a tabulation of the nanoparticles present in the activity along with their interaction pests.

Table 7. Nanoparticles serving as insecticides and pesticides.

Nanoparticles	Activity	Pests Affected	Reference
ZnO	Blocks the organism	*Fusarium graminearum*, *Penicillium expansum*, *Alternaria alternate*, *F. oxysporum*, *Rhizopus stolonifer*, *Mucorplumbeus*, *Pseudomonas aeruginosa* and *Aspergillus flavus*	[127,128,136]
MO	Stops fungal conidiophores and conidia growth on vegetative parts of fungi	Conidia and conidiophores of fungi	[137]
C nanotubes	Raises the nutrients and elemental uptake by plants and is also involved in ameliorating the development of plants		[138,139]
Ag	Used to control agricultural pests and organisms	*Helicoverpaarmigera*, *Ariadne merione*, *Pediculushumanus*, *Aedesstephensi*, *Aedes aegypti*, *Culex quinquefasciatus*, *Lipaphiserysimiwas*, *Plutellaxylostella*, *Helicoverpaarmigera* and *Sitophilus oryzae.*	[140–146]
Cd	Causes larval death of 93.79% at 2400 ppm	*Spodopteralitura*	[147]
TiO_2	Causes larval death of 73.79% at 2400 ppm	*Spodopteralitura*	[147]
Pungam oil-based AuNPs	Causes high mortality of pests	*Pericalliaricini* larvae	[148]
Cu	Causes toxicity against pests	*Triboliumcastaneum*, *Spodopteralittoralis* larvae, *Aedes aegypti* larvae	[149,150]
Nanostructured alumina (Al_2O_3)	Causes mortality when exposed to wheat pests	*Sitophilus oryzae, and Rhizopertha dominica*	[151]
Al	Kills the pest	*S. oryzae*	[152]
TiO_2	Destroys the pest	*S. oryzae*	[152]
Nanosilica	Enters inside the pest from the cuticle, thus destroying the pest	Different pests	[153]
Nanosphere of silica	Helps bactericides to enter into plant cell sap	-	[154]
Bioactive silver	Lags the action of trypsin, hence, makes the pest harmless	Different pests	[155]
AuNPs with protein	Improves catalytic inhibition	-	[155]

4. Conclusions

There is a substantial and adaptable influence of environmentally produced nanoparticles on a range of important fields, such as the development of insecticides and pesticides, the production of biofuel, the inhibition of corrosion, the use of nanofertilizers, the remediation of nano-damaged materials, the facilitation of biodegradation, the detection of heavy metals, and the catalytic reduction of CO_2 to promote the green economy. Utilizing ecofriendly nanomaterials in novel ways highlights their revolutionary potential in advancing sustainability, as well as their ability to address urgent environmental and industrial issues [156]. This research offers a promising path towards a more environmentally conscious and commercially successful future by utilizing the multifaceted properties of green-synthesized nanoparticles. It also strengthens the fundamental role that these nanoparticles will play in forming a more sustainable and greener world by providing comprehensive solutions for a range of industries.

4.1. Future Perspectives

1. Ongoing investigation into novel environmentally friendly nanoparticle production techniques.
2. Researching materials for biodegradable nanoparticles to lessen their influence on the environment.
3. The creation of intelligent nanofertilizers to minimize chemical usage and enable precision farming.
4. Using nanoremediation methods to remediate pollution in water and soil.
5. Improving the biodegradation processes based on nanoparticles to manage waste effectively.
6. Progress in heavy metal identification technology to enhance environmental surveillance.
7. Using catalysts made of nanoparticles to increase the generation of biofuels for sustainable energy.
8. Research how nanoparticles affect ecosystems and microbial communities.
9. Improving and extending the application of nanoparticles in herbicides and insecticides to manage pests.
10. Research on environmentally acceptable and sustainable substitutes for conventional chemical pesticides.
11. Using nanoparticles and catalytic reduction of CO_2 to fight climate change.
12. Examining the possibility of using nanoparticles for carbon collection and usage.
13. Developing rules and policies for the safe and responsible use of nanoparticles.
14. Public awareness initiatives to inform people about the advantages of green nanoparticles as well as any possible hazards.
15. Cooperation to hasten the adoption of green nanoparticles for a greener economy among businesses, academic institutions, and governments.

4.2. Ethical Approval

- The manuscript is not submitted to more than one journal for simultaneous consideration.
- The submitted work is original and should not have been published elsewhere in any form or language (partially or in full).
- A single study has not been split up.
- Results are presented, honestly, and without fabrication, falsification, or inappropriate data manipulation (including image-based manipulation). Authors adhere to discipline-specific rules for acquiring, selecting, and processing data.
- No data, text, or theories by others are presented as if they were the author's own ("plagiarism"). Proper acknowledgements of other works are given.

Author Contributions: M.K.S. and B.S.T. wrote manuscript and prepared concept, J.P. checked grammar and plagiarism, R.L.G. and A.B. proposed concept and executed the idea of this review article. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: A.B. acknowledges TWAS-UNESCO Associateship-Ref. 3240321550 for providing opportunities to visit the Department of Chemistry, Indian Institute of Technology Madras, Chennai, India.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ASTM	American Society for Testing and Materials
ZnO	Zinc Oxide
NPs	Nanoparticles
NFs	Nanofertilizers

References

1. Pearce, D.W.; Markandya, A.; Barbier, E.R. *Blueprint for a Green Economy*; Earthscan Publications Ltd.: London, UK, 1989.
2. Yu, Y.; Li, C.; Fu, Y.; Yang, W. A Group Decision-Making Method to Measure National Energy Architecture Performance: A Case Study of the International Energy Agency. *Appl. Energy* **2023**, *330*, 120285. [CrossRef]
3. Abbas, S.; Saqib, N.; Shahzad, U. Global Export Flow of Chilean Copper: The Role of Environmental Innovation and Renewable Energy Transition. *Geosci. Front.* **2023**, 101697. [CrossRef]
4. Mentes, M. Sustainable Development Economy and the Development of Green Economy in the European Union. *Energy Sustain. Soc.* **2023**, *13*, 32. [CrossRef]
5. De Almeida, S.J.; Esperidião, F.; de Moura, F.R. The Impact of Institutions on Economic Growth: Evidence for Advanced Economies and Latin America and the Caribbean Using a Panel VAR Approach. *Int. Econ.* **2024**, *178*, 100480. [CrossRef]
6. Zaki, B.L.; Dupont, C. Understanding Political Learning by Scientific Experts: A Case of EU Climate Policy. *J. Eur. Public Policy* **2023**, 1–33. [CrossRef]
7. Cui, S.; Wang, Z. The Impact and Transmission Mechanisms of Financial Agglomeration on Eco-Efficiency: Evidence from the Organization for Economic Co-Operation and Development Economies. *J. Clean. Prod.* **2023**, *392*, 136219. [CrossRef]
8. Dai, L.; Chang, D.W.; Baek, J.; Lu, W. Carbon Nanomaterials for Advanced Energy Conversion and Storage. *Small* **2012**, *8*, 1130–1166. [CrossRef]
9. Chausali, N.; Saxena, J.; Prasad, R. Nanotechnology as a Sustainable Approach for Combating the Environmental Effects of Climate Change. *J. Agric. Food Res.* **2023**, *12*, 100541. [CrossRef]
10. Omran, B.A.; Baek, K.-H. Valorization of Agro-Industrial Biowaste to Green Nanomaterials for Wastewater Treatment: Approaching Green Chemistry and Circular Economy Principles. *J. Environ. Manag.* **2022**, *311*, 114806. [CrossRef]
11. Gubitosa, J.; Rizzi, V.; Laurenzana, A.; Scavone, F.; Frediani, E.; Fibbi, G.; Fanelli, F.; Sibillano, T.; Giannini, C.; Fini, P.; et al. The "End Life" of the Grape Pomace Waste Become the New Beginning: The Development of a Virtuous Cycle for the Green Synthesis of Gold Nanoparticles and Removal of Emerging Contaminants from Water. *Antioxidants* **2022**, *11*, 994. [CrossRef] [PubMed]
12. Alsaiari, N.S.; Alzahrani, F.M.; Amari, A.; Osman, H.; Harharah, H.N.; Elboughdiri, N.; Tahoon, M.A. Plant and Microbial Approaches as Green Methods for the Synthesis of Nanomaterials: Synthesis, Applications, and Future Perspectives. *Molecules* **2023**, *28*, 463. [CrossRef]
13. Vijayaram, S.; Razafindralambo, H.; Sun, Y.-Z.; Vasantharaj, S.; Ghafarifarsani, H.; Hoseinifar, S.H.; Raeeszadeh, M. Applications of Green Synthesized Metal Nanoparticles—A Review. *Biol. Trace Elem. Res.* **2023**, *202*, 360–386. [CrossRef] [PubMed]
14. Gour, A.; Jain, N.K. Advances in Green Synthesis of Nanoparticles. *Artif. Cells Nanomed. Biotechnol.* **2019**, *47*, 844–851. [CrossRef] [PubMed]
15. Meyers, M.A.; Mishra, A.; Benson, D.J. Mechanical Properties of Nanocrystalline Materials. *Prog. Mater. Sci.* **2006**, *51*, 427–556. [CrossRef]
16. Patra, J.K.; Baek, K.-H. Green Biosynthesis of Magnetic Iron Oxide (Fe_3O_4) Nanoparticles Using the Aqueous Extracts of Food Processing Wastes under Photo-Catalyzed Condition and Investigation of Their Antimicrobial and Antioxidant Activity. *J. Photochem. Photobiol. B Biol.* **2017**, *173*, 291–300. [CrossRef] [PubMed]
17. Singh, P.; Singh, K.R.; Verma, R.; Singh, J.; Singh, R.P. Efficient Electro-Optical Characteristics of Bioinspired Iron Oxide Nanoparticles Synthesized by Terminalia Chebula Dried Seed Extract. *Mater. Lett.* **2022**, *307*, 131053. [CrossRef]
18. Abdelmigid, H.M.; Morsi, M.M.; Hussien, N.A.; Alyamani, A.A.; Alhuthal, N.A.; Albukhaty, S. Green Synthesis of Phosphorous-Containing Hydroxyapatite Nanoparticles (nHAP) as a Novel Nanofertilizer: Preliminary Assessment on Pomegranate (*Punica granatum* L.). *Nanomaterials* **2022**, *12*, 1527. [CrossRef]
19. Ali, T.; Warsi, M.F.; Zulfiqar, S.; Sami, A.; Ullah, S.; Rasheed, A.; Alsafari, I.A.; Agboola, P.O.; Shakir, I.; Baig, M.M. Green Nickel/Nickel Oxide Nanoparticles for Prospective Antibacterial and Environmental Remediation Applications. *Ceram. Int.* **2022**, *48*, 8331–8340. [CrossRef]
20. Samuel, M.S.; Jose, S.; Selvarajan, E.; Mathimani, T.; Pugazhendhi, A. Biosynthesized Silver Nanoparticles Using Bacillus Amyloliquefaciens; Application for Cytotoxicity Effect on A549 Cell Line and Photocatalytic Degradation of p-Nitrophenol. *J. Photochem. Photobiol. B Biol.* **2020**, *202*, 111642. [CrossRef]
21. Jain, P.; Patidar, B.; Bhawsar, J. Potential of Nanoparticles as a Corrosion Inhibitor: A Review. *J. Bio- Tribo-Corros.* **2020**, *6*, 43. [CrossRef]
22. Rathish, R.J.; Joany RD, R.; Pandiarajan, M.; Rajendran, S. Corrosion resistance of nanoparticle-incorporated nano coatings. *Eur. Chem. Bull.* **2013**, *2*, 965–970.
23. Ituen, E.; Ekemini, E.; Yuanhua, L.; Singh, A. Green Synthesis of Citrus Reticulata Peels Extract Silver Nanoparticles and Characterization of Structural, Biocide and Anticorrosion Properties. *J. Mol. Struct.* **2020**, *1207*, 127819. [CrossRef]
24. Fetouh, H.A.; Hefnawy, A.; Attia, A.M.; Ali, E. Facile and Low-Cost Green Synthesis of Eco-Friendly Chitosan-Silver Nanocomposite as Novel and Promising Corrosion Inhibitor for Mild Steel in Chilled Water Circuits. *J. Mol. Liq.* **2020**, *319*, 114355. [CrossRef]
25. Liao, B.; Cen, H.; Xiang, T.; Dai, H.; Wu, H.; Wan, S.; Guo, X. Functionalized Nanocomposites as Corrosion Inhibitors. In *ACS Symposium Series*; ACS: Washington, DC, USA, 2022; pp. 213–229. [CrossRef]

26. Picchio, M.L.; Minudri, D.; Mantione, D.; Criado-Gonzalez, M.; Guzmán-González, G.; Schmarsow, R.; Müller, A.J.; Tomé, L.C.; Minari, R.J.; Mecerreyes, D. Natural Deep Eutectic Solvents Based on Choline Chloride and Phenolic Compounds as Efficient Bioadhesives and Corrosion Protectors. *ACS Sustain. Chem. Eng.* **2022**, *10*, 8135–8142. [CrossRef]
27. Chen, S.; Wang, J.; Lu, H.; Xu, L. Surfactant-Modified Silica Nanoparticles-Stabilized Magnetic Polydimethylsiloxane-in-Water Pickering Emulsions for Lubrication and Anticorrosion. *ACS Sustain. Chem. Eng.* **2022**, *10*, 10816–10826. [CrossRef]
28. Su, W.; Tang, B.; Fu, F.; Huang, S.; Zhao, S.; Bin, L.; Ding, J.; Chen, C. A New Insight into Resource Recovery of Excess Sewage Sludge: Feasibility of Extracting Mixed Amino Acids as an Environment-Friendly Corrosion Inhibitor for Industrial Pickling. *J. Hazard. Mater.* **2014**, *279*, 38–45. [CrossRef] [PubMed]
29. Chaudhary, P.; Ahamad, L.; Chaudhary, A.; Kumar, G.; Chen, W.-J.; Chen, S. Nanoparticle-Mediated Bioremediation as a Powerful Weapon in the Removal of Environmental Pollutants. *J. Environ. Chem. Eng.* **2023**, *11*, 109591. [CrossRef]
30. Bai, Z.; Wang, X.; Huang, M.; Zheng, M.; Yue, O.; Hao, D.; Wang, Y.; Zou, X.; Cui, B.; Xie, L.; et al. Versatile Nano–Micro Collagen Fiber-Based Wearable Electronics for Health Monitoring and Thermal Management. *J. Mater. Chem. A* **2023**, *11*, 726–741. [CrossRef]
31. Grisolia, A.; Dell'Olio, G.; Spadafora, A.; De Santo, M.; Morelli, C.; Leggio, A.; Pasqua, L. Hybrid Polymer-Silica Nanostructured Materials for Environmental Remediation. *Molecules* **2023**, *28*, 5105. [CrossRef]
32. Soni, A.; Bhandari, M.P.; Tripathi, G.K.; Bundela, P.; Khiriya, P.K.; Khare, P.S.; Kashyap, M.K.; Dey, A.; Vellingiri, B.; Sundaramurthy, S.; et al. Nano-biotechnology in Tumour and Cancerous Disease: A Perspective Review. *J. Cell. Mol. Med.* **2023**, *27*, 737–762. [CrossRef]
33. Singh, A.K.; Rathod, V.; Singh, D.; Ninganagouda, S.; Kulkarni, P.; Mathew, J.; Haq, M.U. Bioactive silver nanoparticles from endophytic fungus *Fusarium* sp. isolated from an ethanomedicinal plant *Withania somnifera* (Ashwagandha) and its antibacterial activity. *Int. J. Nanomater. Biostruct* **2015**, *5*, 15–19.
34. Kokura, S.; Handa, O.; Takagi, T.; Ishikawa, T.; Naito, Y.; Yoshikawa, T. Silver Nanoparticles as a Safe Preservative for Use in Cosmetics. *Nanomed. Nanotechnol. Biol. Med.* **2010**, *6*, 570–574. [CrossRef] [PubMed]
35. Samberg, M.E.; Oldenburg, S.J.; Monteiro-Riviere, N.A. Evaluation of Silver Nanoparticle Toxicity in Skin in Vivo and Keratinocytes in Vitro. *Environ. Health Perspect.* **2010**, *118*, 407–413. [CrossRef] [PubMed]
36. Report ILZSG. *World Directory of Continuous Galvanizing Lines*; ILZSG: New York, NY, USA, 2017.
37. Koch, G.; Varney, J.; Thompson, N.; Moghissi, O.; Gould, M.; Payer, J. *International Measures of Prevention Application and Economics of Corrosion Technologies Study*; NACE International: Houston, TX, USA, 2008.
38. Koch, G. Cost of Corrosion. In *Woodhead Publishing Series in Energy, Trends in Oil and Gas Corrosion Research and Technologies*; Woodhead Publishing: Cambridge, UK, 2017; pp. 3–30.
39. Nishimura, R.; Maeda, Y. Stress Corrosion Cracking of Type 304 Austenitic Stainless Steel in Sulphuric Acid Solution Including Sodium Chloride and Chromate. *Corros. Sci.* **2004**, *46*, 343–360. [CrossRef]
40. Sanyal, B. Organic Compounds as Corrosion Inhibitors in Different Environments—A Review. *Prog. Org. Coat.* **1981**, *9*, 165–236. [CrossRef]
41. Trabanelli, G. Corrosion inhibitors. In *Corrosion Mechanisms*; CRC Press: Boca Raton, FL, USA, 2020; pp. 119–163.
42. Oguzie, E.E. Corrosion Inhibition of Aluminium in Acidic and Alkaline Media by Sansevieria Trifasciata Extract. *Corros. Sci.* **2007**, *49*, 1527–1539. [CrossRef]
43. Obot, I.B.; Obi-Egbedi, N.O.; Umoren, S.A.; Ebenso, E.E. Synergistic and antagonistic effects of anions and Ipomoea invulcrata as green corrosion inhibitor for aluminium dissolution in acidic medium. *Int. J. Electrochem. Sci.* **2010**, *5*, 994–1007. [CrossRef]
44. Alvarez, P.E.; Fiori-Bimbi, M.V.; Neske, A.; Brandán, S.A.; Gervasi, C.A. Rollinia Occidentalis Extract as Green Corrosion Inhibitor for Carbon Steel in HCl Solution. *J. Ind. Eng. Chem.* **2018**, *58*, 92–99. [CrossRef]
45. Chetouani, A.; Hammouti, B. Corrosion inhibition of iron in hydrochloric acid solutions by naturally henna. *Bull. Electrochem.* **2003**, *19*, 23–25.
46. Vickers, N.J. Animal Communication: When I'm Calling You, Will You Answer Too? *Curr. Biol.* **2017**, *27*, R713–R715. [CrossRef]
47. Haldhar, R.; Prasad, D.; Bhardwaj, N. Extraction and Experimental Studies of Citrus Aurantifolia as an Economical and Green Corrosion Inhibitor for Mild Steel in Acidic Media. *J. Adhes. Sci. Technol.* **2019**, *33*, 1169–1183. [CrossRef]
48. Akkalatham, W.; Taghipour, A.; Yongsiri, P.; Ali, S.M. Circular Economy in Materials to Decarbonize Mobility. In *Renewable Energy in Circular Economy*; Springer: Cham, Switzerland, 2023; pp. 89–112. [CrossRef]
49. Thakur, A.; Sharma, S.; Ganjoo, R.; Assad, H.; Kumar, A. Anti-Corrosive Potential of the Sustainable Corrosion Inhibitors Based on Biomass Waste: A Review on Preceding and Perspective Research. *J. Phys. Conf. Ser.* **2022**, *2267*, 012079. [CrossRef]
50. Lateef, A. Cola Nitida: Milestones in Catalysis, Biotechnology and Nanotechnology for Circular Economy and Sustainable Development. *Biocatal. Agric. Biotechnol.* **2023**, *53*, 102856. [CrossRef]
51. de Souza, F.S.; Spinelli, A. Caffeic Acid as a Green Corrosion Inhibitor for Mild Steel. *Corros. Sci.* **2009**, *51*, 642–649. [CrossRef]
52. Raja, P.B.; Rahim, A.A.; Osman, H.; Awang, K. Inhibitive Effect of XylopiaFerruginea Extract on the Corrosion of Mild Steel in 1M HCl Medium. *Int. J. Miner. Metall. Mater.* **2011**, *18*, 413–418. [CrossRef]
53. Kausar, A.; Ahmad, I.; Zhao, T. Corrosion-Resisting Nanocarbon Nanocomposites for Aerospace Application: An Up-to-Date Account. *Appl. Nano* **2023**, *4*, 138–158. [CrossRef]

54. El-Lateef, H.M.A.; Gouda, M. Novel Nanocomposites of Nickel and Copper Oxide Nanoparticles Embedded in a Melamine Framework Containing Cellulose Nanocrystals: Material Features and Corrosion Protection Applications. *J. Mol. Liq.* **2021**, *342*, 116960. [CrossRef]
55. Mrunal, V.K.; Vishnu, A.K.; Momin, N.; Manjanna, J. Cu_2O Nanoparticles for Adsorption and Photocatalytic Degradation of Methylene Blue Dye from Aqueous Medium. *Environ. Nanotechnol. Monit. Manag.* **2019**, *12*, 100265. [CrossRef]
56. Ardekani, P.S.; Karimi, H.; Ghaedi, M.; Asfaram, A.; Purkait, M.K. Ultrasonic Assisted Removal of Methylene Blue on Ultrasonically Synthesized Zinc Hydroxide Nanoparticles on Activated Carbon Prepared from Wood of Cherry Tree: Experimental Design Methodology and Artificial Neural Network. *J. Mol. Liq.* **2017**, *229*, 114–124. [CrossRef]
57. Razali, S.Z.; Aziz, M.Y.; Edinur, H.A.; Razali Ishak, A. Adsorption of Methylene Blue onto Iron Oxide Magnetic Nanoparticles Coated with Sugarcane Bagasse. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *596*, 012052. [CrossRef]
58. Ramesh, A.V.; Rama Devi, D.; Mohan Botsa, S.; Basavaiah, K. Facile Green Synthesis of Fe_3O_4 Nanoparticles Using Aqueous Leaf Extract of *Zanthoxylum armatum* DC. for Efficient Adsorption of Methylene Blue. *J. Asian Ceram. Soc.* **2018**, *6*, 145–155. [CrossRef]
59. Kamaraj, M.; Srinivasan, N.R.; Assefa, G.; Adugna, A.T.; Kebede, M. Facile Development of Sunlit ZnO Nanoparticles-Activated Carbon Hybrid from Pernicious Weed as an Operative Nano-Adsorbent for Removal of Methylene Blue and Chromium from Aqueous Solution: Extended Application in Tannery Industrial Wastewater. *Environ. Technol. Innov.* **2020**, *17*, 100540. [CrossRef]
60. Xu, Z.; He, P.; Yin, X.; Huang, Q.; Ding, W.; Xu, X.; Struik, P.C. Can the Advisory System Nutrient Expert® Balance Productivity, Profitability and Sustainability for Rice Production Systems in China? *Agric. Syst.* **2023**, *205*, 103575. [CrossRef]
61. Řezbová, H.; Slaboch, J.; Mach, J. Emissions from Managed Agricultural Soils in Context of Consumption of Inorganic Nitrogen Fertilisers in Selected EU Countries. *Agronomy* **2023**, *13*, 159. [CrossRef]
62. Smerald, A.; Kraus, D.; Rahimi, J.; Fuchs, K.; Kiese, R.; Butterbach-Bahl, K.; Scheer, C. A Redistribution of Nitrogen Fertiliser across Global Croplands Can Help Achieve Food Security within Environmental Boundaries. *Commun. Earth Environ.* **2023**, *4*, 315. [CrossRef]
63. Higgins, S.; Keesstra, S.D.; Kadziuliene, Ž.; Jordan-Meille, L.; Wall, D.; Trinchera, A.; Spiegel, H.; Sandén, T.; Baumgarten, A.; Jensen, J.L.; et al. Stocktake Study of Current Fertilisation Recommendations across Europe and Discussion towards a More Harmonised Approach. *Eur. J. Soil Sci.* **2023**, *74*, e13422. [CrossRef]
64. Głodniok, M.; Deska, M.; Kaszycki, P. Impact of the Stabilized Sewage Sludge-Based Granulated Fertilizer on *Sinapis alba* Growth and Biomass Chemical Characteristics. *Biol. Life Sci. Forum* **2021**, *3*, 35.
65. Kechasov, D.; Verheul, M.J.; Paponov, M.; Panosyan, A.; Paponov, I.A. Organic Waste-Based Fertilizer in Hydroponics Increases Tomato Fruit Size but Reduces Fruit Quality. *Front. Plant Sci.* **2021**, *12*, 1047. [CrossRef] [PubMed]
66. Piersa, P.; Szufa, S.; Czerwinska, J.; Uenyay, H.; Adrian, L.; Wielgosinski, G.; Obraniak, A.; Lewandowska, W.; Marczak-Grzesik, M.; Dzikuc, M.; et al. Pine Wood and Sewage Sludge Torrefaction Process for Production Renewable Solid Biofuels and Biochar as Carbon Carrier for Fertilizers. *Energies* **2021**, *14*, 8176. [CrossRef]
67. Escribà-Gelonch, M.; Butler, G.D.; Goswami, A.; Tran, N.N.; Hessel, V. Definition of Agronomic Circular Economy Metrics and Use for Assessment for a Nanofertilizer Case Study. *Plant Physiol. Biochem.* **2023**, *196*, 917–924. [CrossRef]
68. Rabalao, T.M.; Ndaba, B.; Roopnarain, A.; Vatsha, B. Towards a Circular Economy: The Influence of Extraction Methods on Phytosynthesis of Metallic Nanoparticles and Their Impact on Crop Growth and Protection. *JSFA Rep.* **2022**, *2*, 208–221. [CrossRef]
69. Jeet, K.; Kumar, V.; Anushree; Devi, R. Valorization of Agricultural Wastes: A Step Toward Adoption of Smart Green Materials with Additional Benefit of Circular Economy. In *Handbook of Biomass Valorization for Industrial Applications*; Wiley: Hoboken, NJ, USA, 2022; pp. 343–367. [CrossRef]
70. Munir, T.; Rizwan, M.; Kashif, M.; Shahzad, A.; Ali, S.; Amin, N.; Zahid, R.; Alam, M.F.E.; Imran, M. Effect of zinc oxide nanoparticles on the growth and Zn uptake in wheat (*Triticum aestivum* L.) by seed priming method. *Dig. J. Nanomater. Biostructures (DJNB)* **2018**, *13*, 315.
71. Khodakovskaya, M.V.; Kim, B.; Kim, J.N.; Alimohammadi, M.; Dervishi, E.; Mustafa, T.; Cernigla, C.E. Carbon Nanotubes as Plant Growth Regulators: Effects on Tomato Growth, Reproductive System, and Soil Microbial Community. *Small* **2012**, *9*, 115–123. [CrossRef] [PubMed]
72. Du, W.; Yang, J.; Peng, Q.; Liang, X.; Mao, H. Comparison Study of Zinc Nanoparticles and Zinc Sulphate on Wheat Growth: From Toxicity and Zinc Biofortification. *Chemosphere* **2019**, *227*, 109–116. [CrossRef]
73. Shebl, A.; Hassan, A.A.; Salama, D.M.; Abd El-Aziz, M.E.; Abd Elwahed, M.S.A. Green Synthesis of Nanofertilizers and Their Application as a Foliar forCucurbitaPepoL. *J. Nanomater.* **2019**, *2019*, 3476347. [CrossRef]
74. Rui, M.; Ma, C.; Hao, Y.; Guo, J.; Rui, Y.; Tang, X.; Zhao, Q.; Fan, X.; Zhang, Z.; Hou, T.; et al. Iron Oxide Nanoparticles as a Potential Iron Fertilizer for Peanut (*Arachis hypogaea*). *Front. Plant Sci.* **2016**, *7*, 815. [CrossRef]
75. Adisa, I.O.; Pullagurala, V.L.R.; Peralta-Videa, J.R.; Dimkpa, C.O.; Elmer, W.H.; Gardea-Torresdey, J.L.; White, J.C. Recent Advances in Nano-Enabled Fertilizers and Pesticides: A Critical Review of Mechanisms of Action. *Environ. Sci. Nano* **2019**, *6*, 2002–2030. [CrossRef]
76. Ghosh, S.K.; Bera, T. Molecular Mechanism of Nanofertilizer in Plant Growth and Development: A Recent Account. In *Advances in Nanofertilizers and Nano-Pesticides in Agriculture*; Woodhead Publishing: New Delhi, India, 2021; pp. 535–560. [CrossRef]
77. Solanki, P.; Bhargava, A.; Chhipa, H.; Jain, N.; Panwar, J. Nanofertilizers and Their Smart Delivery System. In *Nanotechnologies in Food and Agriculture*; Springer: Cham, Switzerland, 2015; pp. 81–101.

78. Zahra, Z.; Habib, Z.; Hyun, H.; Shahzad, H.M.A. Overview on Recent Developments in the Design, Application, and Impacts of Nanofertilizers in Agriculture. *Sustainability* **2022**, *14*, 9397. [CrossRef]
79. Singla, R.; Kumari, A.; Yadav, S.K. Impact of Nanomaterials on Plant Physiology and Functions. In *Nanomaterials and Plant Potential*; Springer: Cham, Swizerland, 2019; pp. 349–377. [CrossRef]
80. Masarovičová, E.; Kráľová, K. Metal Nanoparticles and Plants/NanocząstkiMetaliczne I Rośliny. *Ecol. Chem. Eng. S* **2013**, *20*, 9–22. [CrossRef]
81. Salama, D.M.; Abd El-aziz, M.E.; El-naggar, M.E.; Shaaban, E.A.; Abd El-Wahed, M.S. Synthesis of an Eco-Friendly Nanocomposite Fertilizer for Common Bean Based on Carbon Nanoparticles from Agricultural Waste Biochar. *Pedosphere* **2021**, *31*, 923–933. [CrossRef]
82. Hussein, H.S.; Shaarawy, H.H.; Hussien, N.H.; Hawash, S.I. Preparation of Nanofertilizer Blend from Banana Peels. *Bull. Natl. Res. Cent.* **2019**, *43*, 26. [CrossRef]
83. Abdel-Aziz, H.M.M.; Soliman, M.I.; Abo Al-Saoud, A.M.; El-Sherbeny, G.A. Waste-Derived NPK Nanofertilizer Enhances Growth and Productivity of *Capsicum annuum* L. *Plants* **2021**, *10*, 1144. [CrossRef] [PubMed]
84. Pais, M.; George, S.D.; Rao, P. Glycogen Nanoparticles as a Potential Corrosion Inhibitor. *Int. J. Biol. Macromol.* **2021**, *182*, 2117–2129. [CrossRef] [PubMed]
85. Surendhiran, S.; Gowthambabu, V.; Balamurugan, A.; Sudha, M.; Senthil Kumar, V.B.; Suresh, K.C. Rapid Green Synthesis of CuO Nanoparticles and Evaluation of Its Photocatalytic and Electrochemical Corrosion Inhibition Performance. *Mater. Today Proc.* **2021**, *47*, 1011–1016. [CrossRef]
86. Syed Khadar, Y.A.; Surendhiran, S.; Gowthambabu, V.; Halimabi Alias Shakila Banu, S.; Devabharathi, V.; Balamurugan, A. Enhancement of Corrosion Inhibition of Mild Steel in Acidic Media by Green-Synthesized Nano-Manganese Oxide. *Mater. Today Proc.* **2021**, *47*, 889–893. [CrossRef]
87. Ungureanu, C.; Tihan, G.T.; Zgârian, R.G.; Fierascu, I.; Baroi, A.M.; Răileanu, S.; Fierăscu, R.C. Metallic and Metal Oxides Nanoparticles for Sensing Food Pathogens—An Overview of Recent Findings and Future Prospects. *Materials* **2022**, *15*, 5374. [CrossRef] [PubMed]
88. Ciani, M.; Adessi, A. Cyanoremediation and Phyconanotechnology: Cyanobacteria for Metal Biosorption toward a Circular Economy. *Front. Microbiol.* **2023**, *14*, 1166612. [CrossRef]
89. Maddaloni, M.; Alessandri, I.; Vassalini, I. Food-Waste Enables Carboxylated Gold Nanoparticles to Completely Abat Hexavalent Chromium in Drinking Water. *Environ. Nanotechnol. Monit. Manag.* **2022**, *18*, 100686. [CrossRef]
90. Lokhande, R.S.; Singare, P.U.; Pimple, D.S. Toxicity study of heavy metals pollutants in wastewater effluent samples collected from Taloja industrial estate of Mumbai, India. *Resour. Environ.* **2011**, *1*, 13–19.
91. Zhang, S.; Wang, J.; Zhang, Y.; Ma, J.; Huang, L.; Yu, S.; Chen, L.; Song, G.; Qiu, M.; Wang, X. Applications of Water-Stable Metal-Organic Frameworks in the Removal of Water Pollutants: A Review. *Environ. Pollut.* **2021**, *291*, 118076. [CrossRef]
92. Salazar Sandoval, S.; Bruna, T.; Maldonado-Bravo, F.; Jara, P.; Caro, N.; Rojas-Romo, C.; González-Casanova, J.; Gómez, D.R.; Yutronic, N.; Urzúa, M.; et al. Nanomaterials for Potential Detection and Remediation: A Review of Their Analytical and Environmental Applications. *Coatings* **2023**, *13*, 2085. [CrossRef]
93. Fu, L.; Li, X.; Yu, J.; Ye, J. Facile and Simultaneous Stripping Determination of Zinc, Cadmium and Lead on Disposable Multiwalled Carbon Nanotubes Modified Screen-Printed Electrode. *Electroanalysis* **2013**, *25*, 567–572. [CrossRef]
94. Xiao, L.; Wildgoose, G.G.; Compton, R.G. Sensitive Electrochemical Detection of Arsenic (III) Using Gold Nanoparticle Modified Carbon Nanotubes via Anodic Stripping Voltammetry. *Anal. Chim. Acta* **2008**, *620*, 44–49. [CrossRef]
95. Wang, D.; Zhao, Y.; Jin, H.; Zhuang, J.; Zhang, W.; Wang, S.; Wang, J. Synthesis of Au-Decorated Tripod-Shaped Te Hybrids for Applications in the Ultrasensitive Detection of Arsenic. *ACS Appl. Mater. Interfaces* **2013**, *5*, 5733–5740. [CrossRef]
96. Yu, C.-J.; Tseng, W.-L. Colorimetric Detection of Mercury(II) in a High-Salinity Solution Using Gold Nanoparticles Capped with 3-Mercaptopropionate Acid and Adenosine Monophosphate. *Langmuir* **2008**, *24*, 12717–12722. [CrossRef]
97. Hong, S.; Park, S.; Lee, S.; Yang, Y.I.; Song, H.D.; Yi, J. The Sensitive, Anion-Selective Detection of Arsenate with Poly(Allylamine Hydrochloride) by Single Particle Plasmon-Based Spectroscopy. *Anal. Chim. Acta* **2011**, *694*, 136–141. [CrossRef]
98. Teng, Y.; Zhang, Y.; Zhou, K.; Yu, Z. Screen Graphene-Printed Electrode for Trace Cadmium Detection in Rice Samples Combing with Portable Potentiostat. *Int. J. Electrochem. Sci.* **2018**, *13*, 6347–6357. [CrossRef]
99. Ruengpirasiri, P.; Punrat, E.; Chailapakul, O.; Chuanuwatanakul, S. Graphene Oxide-Modified Electrode Coated with In-situ Antimony Film for the Simultaneous Determination of Heavy Metals by Sequential Injection-Anodic Stripping Voltammetry. *Electroanalysis* **2016**, *29*, 1022–1030. [CrossRef]
100. Chen, K.; Lu, G.; Chang, J.; Mao, S.; Yu, K.; Cui, S.; Chen, J. Hg(II) Ion Detection Using Thermally Reduced Graphene Oxide Decorated with Functionalized Gold Nanoparticles. *Anal. Chem.* **2012**, *84*, 4057–4062. [CrossRef]
101. Pérez-Ràfols, C.; Serrano, N.; Díaz-Cruz, J.M.; Ariño, C.; Esteban, M. A Screen-Printed Voltammetric Electronic Tongue for the Analysis of Complex Mixtures of Metal Ions. *Sens. Actuators B Chem.* **2017**, *250*, 393–401. [CrossRef]
102. Deshmukh, M.K.G.; Sameeroddin, M.; Abdul, D.; Sattar, M.A. Renewable energy in the 21st century: A review. *Mater. Today Proc.* **2023**, *80*, 1756–1759. [CrossRef]
103. Scarlat, N.; Dallemand, J.-F. Future Role of Bioenergy. In *The Role of Bioenergy in the Bioeconomy*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 435–547.

104. Duarah, P.; Haldar, D.; Patel, A.K.; Dong, C.-D.; Singhania, R.R.; Purkait, M.K. A review on global perspectives of sustainable development in bioenergy generation. *Bioresour. Technol.* **2022**, *348*, 126791. [CrossRef]
105. Holechek, J.L.; Geli, H.M.E.; Sawalhah, M.N.; Valdez, R.A. Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050? *Sustainability* **2022**, *14*, 4792. [CrossRef]
106. Masson-Delmotte, V.; Zhai, P.; Pörtner, H.-O.; Roberts, D.; Skea, J.; Shukla, P.R.; Pirani, A.; Moufouma-Okia, W.; Péan, C.; Pidcock, R.; et al. *Global Warming of 1.5 °C.*; International Panel on Climate Change: Geneva, Switzerland, 2018.
107. Ripple, W.J.; Wolf, C.; Newsome, T.W.; Gregg, J.W.; Lenton, M.; Barnard, P.; Moomaw, W.R. World scientists warning of climate emergency 2021. *BioScience* **2021**, *71*, 894–898. [CrossRef]
108. World Population Clock. Available online: https://www.worldometers.info/world-population/ (accessed on 8 April 2023).
109. Berahab, R. *Global Trends in the Energy Sector and Their Implication on Energy Security in NATO's Southern Neighbourhood*; Elcano Royal Institute: Madrid, Spain, 2020.
110. European Commission. *'Fit for 55' Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality*; Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions Empty; European Commision: Brussels, Berlgium, 2021.
111. Mujtaba, M.; Fernandes Fraceto, L.; Fazeli, M.; Mukherjee, S.; Savassa, S.M.; Araujo de Medeiros, G.; do Espírito Santo Pereira, A.; Mancini, S.D.; Lipponen, J.; Vilaplana, F. Lignocellulosic Biomass from Agricultural Waste to the Circular Economy: A Review with Focus on Biofuels, Biocomposites and Bioplastics. *J. Clean. Prod.* **2023**, *402*, 136815. [CrossRef]
112. Arya, I.; Poona, A.; Dikshit, P.K.; Pandit, S.; Kumar, J.; Singh, H.N.; Jha, N.K.; Rudayni, H.A.; Chaudhary, A.A.; Kumar, S. Current Trends and Future Prospects of Nanotechnology in Biofuel Production. *Catalysts* **2021**, *11*, 1308. [CrossRef]
113. Mena-Cervantes, V.Y.; Hernández-Altamirano, R.; García-Solares, S.M.; Arreola-Valerio, E. Biodiesel in Circular Economy. In *Biofuels in Circular Economy*; Springer: Singapore, 2022; pp. 251–278. [CrossRef]
114. Rozina; Chia, S.R.; Ahmad, M.; Sultana, S.; Zafar, M.; Asif, S.; Bokhari, A.; Nomanbhay, S.; Mubashir, M.; Khoo, K.S.; et al. Green Synthesis of Biodiesel from Citrus Medica Seed Oil Using Green Nanoparticles of Copper Oxide. *Fuel* **2022**, *323*, 124285. [CrossRef]
115. Liu, Z.; Lv, F.; Zheng, H.; Zhang, C.; Wei, F.; Xing, X.-H. Enhanced Hydrogen Production in a UASB Reactor by Retaining Microbial Consortium onto Carbon Nanotubes (CNTs). *Int. J. Hydrogen Energy* **2012**, *37*, 10619–10626. [CrossRef]
116. Rai, M.; Ingle, A.P.; Birla, S.; Yadav, A.; Santos, C.A.D. Strategic Role of Selected Noble Metal Nanoparticles in Medicine. *Crit. Rev. Microbiol.* **2015**, *42*, 696–719. [CrossRef] [PubMed]
117. Shakeel, N.; Ahamed, M.I.; Ahmed, A.; Inamuddin; Rahman, M.; Asiri, A.M. Functionalized Magnetic Nanoparticle-Reduced Graphene Oxide Nanocomposite for Enzymatic Biofuel Cell Applications. *Int. J. Hydrogen Energy* **2019**, *44*, 28294–28304. [CrossRef]
118. Dantas, J.; Leal, E.; Mapossa, A.B.; Cornejo, D.R.; Costa, A.C.F.M. Magnetic Nanocatalysts of $Ni_{0.5}$Zn0.5Fe_2O_4 Doped with Cu and Performance Evaluation in Transesterification Reaction for Biodiesel Production. *Fuel* **2017**, *191*, 463–471. [CrossRef]
119. Cherian, E.; Dharmendirakumar, M.; Baskar, G. Immobilization of Cellulase onto MnO_2 Nanoparticles for Bioethanol Production by Enhanced Hydrolysis of Agricultural Waste. *Chin. J. Catal.* **2015**, *36*, 1223–1229. [CrossRef]
120. Wang, T.; Jin, X.; Chen, Z.; Megharaj, M.; Naidu, R. Green Synthesis of Fe Nanoparticles Using Eucalyptus Leaf Extracts for Treatment of Eutrophic Wastewater. *Sci. Total Environ.* **2014**, *466–467*, 210–213. [CrossRef] [PubMed]
121. Hou, J.; Yang, Y.; Wang, P.; Wang, C.; Miao, L.; Wang, X.; Lv, B.; You, G.; Liu, Z. Effects of CeO2, CuO, and ZnO Nanoparticles on Physiological Features of Microcystis Aeruginosa and the Production and Composition of Extracellular Polymeric Substances. *Environ. Sci. Pollut. Res.* **2016**, *24*, 226–235. [CrossRef] [PubMed]
122. Sugsaisakon, S.; Kittipongvises, S. Impacts of the Nationally Determined Contribution to the 1.5 °C Climate Goal and Net-Zero Target on Citywide Greenhouse Gas Emissions: A Case Study on Bangkok, Thailand. *Environ. Dev. Sustain.* 2024; 1–18. [CrossRef]
123. Baby, R.; Hussein, M.Z.; Abdullah, A.H.; Zainal, Z. Nanomaterials for the Treatment of Heavy Metal Contaminated Water. *Polymers* **2022**, *14*, 583. [CrossRef]
124. Sai Ram, M.; Singh, L.; Suryanarayana, M.V.S.; Alam, S.I. Effect of Iron, Nickel and Cobalt on Bacterial Activity and Dynamics During Anaerobic Oxidation of Organic Matter. *Water Air Soil Pollut.* **2000**, *117*, 305–312. [CrossRef]
125. Hart, A. Circular Economy: Closing the Catalyst Loop with Metal Reclamation from Spent Catalysts, Industrial Waste, Waste Shells and Animal Bones. *Biomass Convers. Biorefinery* **2021**, *13*, 11483–11498. [CrossRef]
126. Wrasman, C.J.; Wilson, A.N.; Mante, O.D.; Iisa, K.; Dutta, A.; Talmadge, M.S.; Dayton, D.C.; Uppili, S.; Watson, M.J.; Xu, X.; et al. Catalytic Pyrolysis as a Platform Technology for Supporting the Circular Carbon Economy. *Nat. Catal.* **2023**, *6*, 563–573. [CrossRef]
127. Chen, Z.; Yun, S.; Wu, L.; Zhang, J.; Shi, X.; Wei, W.; Liu, Y.; Zheng, R.; Han, N.; Ni, B.-J. Waste-Derived Catalysts for Water Electrolysis: Circular Economy-Driven Sustainable Green Hydrogen Energy. *Nano-Micro Lett.* **2022**, *15*, 4. [CrossRef]
128. Dwivedi, S.; Saquib, Q.; Al-Khedhairy, A.A.; Musarrat, J. Understanding the Role of Nanomaterials in Agriculture. In *Microbial Inoculants in Sustainable Agricultural Productivity*; Springer: New Delhi, India, 2016; pp. 271–288. [CrossRef]
129. Suzuki, T.M.; Ishizaki, T.; Kosaka, S.; Takahashi, N.; Isomura, N.; Seki, J.; Matsuoka, Y.; Oh-ishi, K.; Oshima, A.; Kitazumi, K.; et al. Electrochemical CO_2 Reduction over Nanoparticles Derived from an Oxidized Cu–Ni Intermetallic Alloy. *Chem. Commun.* **2020**, *56*, 15008–15011. [CrossRef]
130. Servin, A.; Elmer, W.; Mukherjee, A.; De la Torre-Roche, R.; Hamdi, H.; White, J.C.; Bindraban, P.; Dimkpa, C. A Review of the Use of Engineered Nanomaterials to Suppress Plant Disease and Enhance Crop Yield. *J. Nanoparticle Res.* **2015**, *17*, 92. [CrossRef]

131. Wang, Y.; Jia, H.; Chen, P.; Fang, X.; Du, T. Synthesis of La and Ce Modified X Zeolite from Rice Husk Ash for Carbon Dioxide Capture. *J. Mater. Res. Technol.* **2020**, *9*, 4368–4378. [CrossRef]
132. Hsieh, S.-L.; Li, F.-Y.; Lin, P.-Y.; Beck, D.E.; Kirankumar, R.; Wang, G.-J.; Hsieh, S. CaO Recovered from Eggshell Waste as a Potential Adsorbent for Greenhouse Gas CO_2. *J. Environ. Manag.* **2021**, *297*, 113430. [CrossRef]
133. Eurostat. 2021. Available online: https://ec.europa.eu/eurostat/databrowser/view/AEI_FM_SALPEST09/default/table?lang=en (accessed on 20 May 2021).
134. Kim, Y.; Tanaka, K.; Matsuoka, S. Environmental and economic effectiveness of the Kyoto Protocol. *PLoS ONE* **2020**, *15*, e0236299. [CrossRef] [PubMed]
135. Gross, M. Food security in the times of climate change. *Curr. Biol.* **2013**, *23*, R1–R4. [CrossRef] [PubMed]
136. Vanathi, P.; Rajiv, P.; Sivaraj, R. Synthesis and Characterization of Eichhornia-Mediated Copper Oxide Nanoparticles and Assessing Their Antifungal Activity against Plant Pathogens. *Bull. Mater. Sci.* **2016**, *39*, 1165–1170. [CrossRef]
137. Hassan, S.; Karaila, G.K.; Singh, P.; Meenatchi, R.; Venkateswaran, A.S.; Ahmed, T.; Bansal, S.; Kamalraj, R.; Kiran, G.S.; Selvin, J. Implications of Fungal Nanotechnology for Sustainable Agriculture- Applications and Future Perspectives. *Biocatal. Agric. Biotechnol.* **2024**, 103110. [CrossRef]
138. Intisar, A.; Ramzan, A.; Sawaira, T.; Kareem, A.T.; Hussain, N.; Din, M.I.; Bilal, M.; Iqbal, H.M.N. Occurrence, Toxic Effects, and Mitigation of Pesticides as Emerging Environmental Pollutants Using Robust Nanomaterials—A Review. *Chemosphere* **2022**, *293*, 133538. [CrossRef]
139. Bindra, H.S.; Singh, B. Nanofertilizers and Nanopesticides: Future of Plant Protection. In *Advances in Nanofertilizers and Nano-Pesticides in Agriculture*; Woodhead Publishing: New Delhi, India, 2021; pp. 57–84. [CrossRef]
140. Moorthi, P.V.; Balasubramanian, C.; Mohan, S. An Improved Insecticidal Activity of Silver Nanoparticle Synthesized by Using SargassumMuticum. *Appl. Biochem. Biotechnol.* **2014**, *175*, 135–140. [CrossRef]
141. Devi, G.D.; Murugan, K.; Selvam, C.P. Green synthesis of silver nanoparticles using Euphorbia hirta (Euphorbiaceae) leaf extract against crop pest of cotton bollworm, Helicoverpaarmigera (Lepidoptera: Noctuidae). *J. Biopestic.* **2014**, *7*, 54.
142. Madhiyazhagan, P.; Murugan, K.; Kumar, A.N.; Nataraj, T.; Dinesh, D.; Panneerselvam, C.; Subramaniam, J.; Kumar, P.M.; Suresh, U.; Roni, M.; et al. *S argassum muticum*-Synthesized Silver Nanoparticles: An Effective Control Tool against Mosquito Vectors and Bacterial Pathogens. *Parasitol. Res.* **2015**, *114*, 4305–4317. [CrossRef] [PubMed]
143. Kamil, D.; Prameeladevi, T.; Ganesh, S.; Prabhakaran, N.; Nareshkumar, R.; Thomas, S.P. *Green Synthesis of Silver Nanoparticles by Entomopathogenic Fungus Beauveria bassiana and Their Bioefficacy against Mustard Aphid (Lipaphis erysimi Kalt.)*; NISCAIR-CSIR: New Delhi, India, 2017.
144. Roni, M.; Murugan, K.; Panneerselvam, C.; Subramaniam, J.; Nicoletti, M.; Madhiyazhagan, P.; Dinesh, D.; Suresh, U.; Khater, H.F.; Wei, H.; et al. Characterization and Biotoxicity of HypneaMusciformis-Synthesized Silver Nanoparticles as Potential Eco-Friendly Control Tool against Aedes Aegypti and PlutellaXylostella. *Ecotoxicol. Environ. Saf.* **2015**, *121*, 31–38. [CrossRef] [PubMed]
145. Siva, C.; Kumar, M.S.; Nagar, G.; Nadu, T.; Nagar, G.; Nadu, T. The pesticidal activity of eco-friendly synthesized silver nanoparticles using Aristolochiaindica extracts against HelicoverpaarmigeraHubner (Lepidoptera: Noctuidae). *Int. J. Adv. Sci. Tech. Res.* **2015**, *2*, 197–226.
146. Zahir, A.A.; Bagavan, A.; Kamaraj, C.; Elango, G.; Rahuman, A.A. Efficacy of plant-mediated synthesized silver nanoparticles against Sitophilus oryzae. *J. Biopestic.* **2012**, *5*, 95.
147. Chandrashekharaiah, M.; Kandakoor, S.B.; Basana Gowda, G.; Kammar, V.; Chakravarthy, A.K. Nanomaterials: A Review of Their Action and Application in Pest Management and Evaluation of DNA-Tagged Particles. In *New Horizons in Insect Science: Towards Sustainable Pest Management*; Springer: New Delhi, India, 2015; pp. 113–126. [CrossRef]
148. Sahayaraj, K.; Madasamy, M.; Anbu Radhika, S. Insecticidal activity of bio-silver and gold nanoparticles against *Pericallia ricini* fab. (Lepidaptera: Archidae). *J. Biopestic.* **2016**, *9*, 63–72. [CrossRef]
149. El-Saadony, M.T.; Abd El-Hack, M.E.; Taha, A.E.; Fouda, M.M.G.; Ajarem, J.S.; Maodaa, S.N.; Allam, A.A.; Elshaer, N. Ecofriendly Synthesis and Insecticidal Application of Copper Nanoparticles against the Storage Pest TriboliumCastaneum. *Nanomaterials* **2020**, *10*, 587. [CrossRef] [PubMed]
150. Muthamil Selvan, S.; Vijai Anand, K.; Govindaraju, K.; Tamilselvan, S.; Kumar, V.G.; Subramanian, K.S.; Kannan, M.; Raja, K. Green Synthesis of Copper Oxide Nanoparticles and Mosquito Larvicidal Activity against Dengue, Zika and Chikungunya Causing Vector Aedes Aegypti. *IET Nanobiotechnol.* **2018**, *12*, 1042–1046. [CrossRef] [PubMed]
151. Stadler, T.; Buteler, M.; Weaver, D.K. Novel Use of Nanostructured Alumina as an Insecticide. *Pest Manag. Sci.* **2010**, *66*, 577–579. [CrossRef]
152. Hamza, R.Z.M.M. Larvicidal, antioxidant activities and perturbation of transaminases activities of titanium dioxide nanoparticles synthesized using Moringa oleifera leaves extract against the red palm WEEVIL (Rhynchophorusferrugineus). *Innovare Acad. Sci.* **2015**, 49–54.
153. Nair, R.; Varghese, S.H.; Nair, B.G.; Maekawa, T.; Yoshida, Y.; Kumar, D.S. Nanoparticulate Material Delivery to Plants. *Plant Sci.* **2010**, *179*, 154–163. [CrossRef]
154. Santiago, E.F.; Pontes, M.S.; Arruda, G.J.; Caires, A.R.L.; Colbeck, I.; Maldonado-Rodriguez, R.; Grillo, R. Understanding the Interaction of Nanopesticides with Plants. In *Nanopesticides*; Springer: Cham, Switzerland, 2020; pp. 69–109. [CrossRef]

155. Patil, C.D.; Borase, H.P.; Suryawanshi, R.K.; Patil, S.V. Trypsin Inactivation by Latex Fabricated Gold Nanoparticles: A New Strategy towards Insect Control. *Enzym. Microb. Technol.* **2016**, *92*, 18–25. [CrossRef] [PubMed]
156. Hák, T.; Janoušková, S.; Moldan, B. Sustainable Development Goals: A Need for Relevant Indicators. *Ecol. Indic.* **2016**, *60*, 565–573. [CrossRef]