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Is Nano-Management a Sustainable Solution for Mitigation of Climate Change under the Water-Energy-Food Nexus?

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NATURAL resources are considered the main sources of our life, which include water, energy and food. On the other hand, exponential global human population has place increased stress on such resources and therefore all nations ae enforced to double the productivity of fresh water, clean energy, and healthy food by more than 50-70% to meet their actual needs. These increases are not so easy to be achieved, particularly under climate change. Several approaches are proposed to mitigate the climate change under the Water-Energy-Food (WEF) nexus especially via applying nanomaterials (NMs). This review article describes the evaluation and implementation of applying NMs under climate change in search of suitable proposals to remedy these problems by analyzing the available literature of WEF nexus. The evidences that support the relationship between NMs with WEF nexus and climate change seem weak and/or inconclusive. What is not yet understood is the relative importance of the various factors that might support the global efforts to mitigate climate change and it environmental issues. Many of the available literatures on WEF nexus deal with the question of what are the direct and indirect impacts of climate change on WEF resources, but what remains still unclear is whether applied NMs is a suitable solution or not? The single most striking observation to emerge from the data comparison was several previous studies confirmed the importance of NMs for the environmental problems under certain doses. So far, more studies are needed to explore the relationship between WEF nexus and climate change after applying NMs. In view of all that has been mentioned so far, one may suppose that applied NMs are crucial for conserving WEF resources, but the nanotoxicity is a serious threat should be considered in the further studies.

Keywords: Water resources, Energy resources, Food security, Sustainability, Nano-farming.

1. Introduction

Due to the incredible increase in the global population along with urbanization, industrialization, changing lifestyles, modern intensive agriculture, cultural and technological changes, a high depletion rate was noticed in almost all non-renewable natural resources including energy, water, food, gases, and fossil fuels (Lalawmpuii and Rai 2023). It is estimated that, the demand for energy, food and water

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will increase by more than 70, 50, and 50% by 2050, respectively (Cansino-Loeza et al. 2020; Okonkwo et al. 2023). The global society faces an unprecedented threat in resource depletion because of the exacerbated consumption of water, energy, and food resources along with this rapid growth in global population, urbanization, and industrialization (Fouladi et al. 2023). Thus, a necessitated global need for integration of Water-Energy-Food (WEF) nexus as reported by several studies due to the inextricable relationship among these essential resources (e.g., David et al. 2022; Fouladi et al. 2022; Caixeta et al. 2023). An excessive exploitation on these previous resources has been widely observed to be included the global resilience in energy, water availability, food supply and demand along with the socio-economic sector. WEF nexus is considered an important approach for addressing climate action, combating environmental degradation, and achieving the Sustainable Development Goals (SDGs) (Lalawmpuii and Rai 2023).

Climate change is considered the most important global challenge facing the planet and has a serious impact on the WEF resources. It is reported that climate change has inextricably been linked with perturbations in energy, water, and food sectors (Lalawmpuii and Rai 2023). Under WEF nexus at global scale, it is estimated that 844, 1100, and 815 million people do not have secure access to safe drinking water, clean energy, and food, respectively (Lalawmpuii and Rai 2023). The crucial impact of climate change on WEF nexus was confirmed in several studies such as socio-economic development of WEF nexus under climate change (Han et al. 2022), managing agro-wastes under WEF nexus (El-Ramady et al. 2022), climate and WEF-land nexus (Akbar et al. 2023), WEF nexus and climate change (Herrera-Franco et al. 2023), risks of climate on WEF nexus (Le et al. 2023), agro-adaptations to climate change under WEF nexus (Wu 2023), sustainable desalination under climate-WEF nexus (Zolghadr-Asli et al. 2023), water crisis under WEF-Land-Climate nexus (Barati et al. 2023), crop residues impact on WEF-Carbon nexus under climate warming (Zhou et al. 2023), bioeconomy of WEF nexus under climate change (Ngammuangtueng et al. 2023), and biotech-applications of mushrooms under WEF nexus(Llanaj et al. 2023).

Can nanomaterials (NMs) enhance performing the water-energy-food nexus under disproportionate distribution of WEF-resources? Can nano-management a sustainable solution to improve the efficiency of the WEF-resources, and to decrease the carbon footprint? An increased studies can be noticed on applying nanomaterials for the WEF nexus and its improvements. These reports may include nano-sensing technologies for managing FEW resources (Gouma et al. 2016), applied engineered-NMs for WEF nexus (Bandala and Berli 2019), integration of the nanotechnology approach to enhance WEF nexus (Okonkwo et al. 2021), green synthesis of carbon nanotubes for WEF nexus (Makgabutlane et al. 2021). Many studies published in each sector under applying NMs were reported including improving food production (Ngasotter et al. 2023), for energy generation (Sathish et al. 2023), and removing pollutants from water (Yaashikaa and Kumar 2022; Tatarchuk et al. 2023).

Therefore, this review focuses on the expected and possible role of applied nanomaterials (NMs) for improving the performance of the WEF nexus in particularly under climate change. Nano management of each sector from WEF resources under climate change will be also highlighted. The subjected problems of intensive applied NMs on the environment will be also discussed in the three main sectors.

2. Water-Energy-Food Nexus

What is the main role of WEF-nexus in managing the environmental challenges particularly under climate change (Lalawmpuii and Rai 2023). More questions on the WEF-nexus are listed in **Table 1**. The WEF-nexus has gained a distinguished concern as a crucial approach to manage of water, energy, and food resources more holistically (**Figure 1**). This WEF-nexus promotes the collaboration and coordination across its constituent sectors to identify synergies, trade-offs, and the most beneficial policies across all previous sectors (Lodge et al. 2023). Definitely, there is no any sustainability or achieving the Sustainable Development Goals (SDGs) without referring to WEF-nexus. Many published reports confirmed the vital role of WEF-nexus for achieving these SDGs on different levels such as Cansino-Loeza et al. (2020), Malagó et al. (2021), Akbar et al. (2023), Vargas et al. (2023), and Lalawmpuii and Rai (2023).

Table 1: Recent studies on water-energy- food nexus on different levels and main topics.

Level of study	Main question answered by the article	References
China	Is possible to use the quantitative evaluation and spatial matching of supply-demand of ecosystem services under WEF-nexus in Hangzhou, China?	Ding and Chen (2023)
Global level	Is macro-index a vital tool for exploring the interactions between the WEF-resources, sustainable development, and human development?	Ramírez-Márquez and Ponce-Ortega (2023)
China	What are the key obstacle factors and their dynamic evolution on the cooperative security of WEF-nexus in Southwest China?	Wang and Zhang (2023)
China	What are the main obstacle factors of coordinated development of regional WEF–ecology nexus in Tianjin, China?	Lv et al. (2023)
Global level	What is the role of sustainability of any economy under the WEF-nexus?	Morales-García and Rubio (2023)
Global level	What is the suitable Energy simulation modeling can be used for WEF-nexus system?	Vahabzadeh et al. (2023)
The USA	What are the expected climate risks concerning price risk transmissions in the WEF nexus?	Le et al. (2023)
Global level	Is it possible for decision-making processes apply an approach on WEF nexus and climate change?	Herrera-Franco et al. (2023)
Pakistan level	Can climate incorporate in the WEF-land nexus as an inclusive approach for integrated systems?	Akbar et al. (2023)
Global level	What is the expected role of WEF-nexus for the environmental management and climate action?	Lalawmpuii and Rai (2023)
Brazil and Kenya	Can WEF nexus evaluate using business models for a sustainability maturity evaluation of ten agri-food companies from Brazil and Kenya?	Caixeta et al. (2023)
Multi-level	What is the multi-level approach on study the WEF nexus from molecule to governance?	Okonkwo et al. (2023)
Qatar	What is the sustainable WEF-nexus integration and carbon management in eco-industrial parks?	Fouladi et al. (2023)
Global level	What is the possible modelling of the WEF nexus using global data sources?	Lodge et al. (2023)
China	What are the essential items should be considered for an integrated assessment index system for agricultural system based under WEF nexus in China?	Gao et al. (2023)
Global level	What are the possible methodological tools for evaluating the WEF-One Health nexus in transboundary water Basins?	Bwire et al. (2023)
Iran	Can the sustainable agro-production be achieved using the WEF-nexus with integrated approach to agricultural economic growth and the environment?	Naghavi et al. (2023)

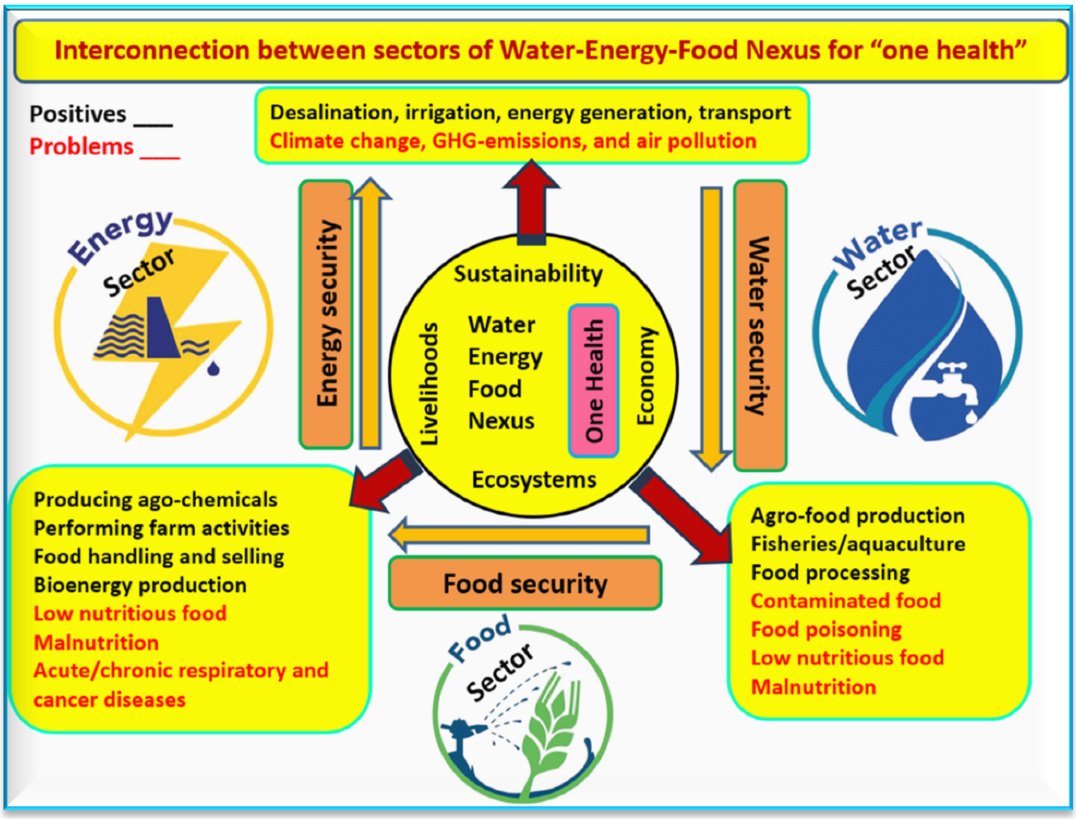

Fig. 1. A strong link between water, energy and food sectors under the concept of "one health".

3.2 Nano management of water sector

It is well known that water is the life, and without it no life exists. This Water is a natural resource that has no substitute or equivalent in the universe. Everything is created from water and must return back to soil, and this is the main fact of our life. All natural resources of water are potentially useful for the life of humans, animals and plants (**Figure 2**). Natural sources of fresh water mainly include surface water (lake, river and fresh water wetland), groundwater, under river flow, and frozen water, whereas the artificial sources may involve reused or treated wastewater, brackish water, stormwater, desalinated seawater, contaminated fresh water, and seawater (Qu et al. 2013).

This is the responsibility of entire members in our global society to manage all available resources beside of searching new non-traditional resources for human life (Müller Schmied et al. 2021). Climate change can affect the global water security throughout considerable changing in frequency and intensity of the temperature and precipitation, leading to floods in some places and droughts in others. Such climatic features change the available amount of freshwater causing a decrease in storage, and groundwater augmentation, as well as deterioration in water quality (Stringer et al. 2021). These climatic impacts are mainly common in the drylands including arid-, semi-arid, hyper-arid, and dry sub-humid parts, where more than 1–2 billion people globally suffer from water scarcity (Stringer et al. 2021).

Water management expresses how to plan, develop, distribute and manage the optimum use of different water resources (Marx et al. 2023). Water resource management can be achieved via applying different technologies in removing pollutants from industrial wastewater (**Table 2**) such as adsorption and nano-adsorbents, photocatalysis and advanced oxidation techniques, nanomembrane and nano-filtration, electrochemical degradation (Kumar et al. 2023). Applied nanomaterials were confirmed in wastewater treatment (Yaqoob et al. 2020; Singh and Gurjar 2023), removing pollutants (Yaashikaa and Kumar 2022), and purification of drinking water (Fu et al. 2022). Many recent reviews reported on the wastewater treatment depending on the main topic of this review such as sustainable clay-based geopolymers (Maged et al. 2023), bio-polymerized metallic nano-architecture (Emmanuel et al. 2023), MXene and nano-zero-valent iron materials (Rameshwar et al. 2023), biochar-based nanocomposites as photocatalytic degradators (Amdeha 2023), nanomaterials for treating pharmaceutical wastewater (Kumar et al. 2023), laccase immobilized on nanocomposites (Zhang et al. 2023), TiO_2-NMs and their photocatalytic properties (Kumar and Chanana 2023), and CuO nano-sorbents (Tarighat et al. 2023).

Nanomaterials have high efficiency in removing water pollutants due to their promising properties, which are considered effective nano-adsorbents for transformations during water purification and/or helpful in wastewater treatment. These characterizers may include higher surface area comparing with traditionally formed-NPs, presence of many functional groups and exhibiting higher selectivity recyclable groups for reducing the toxic ions and elements in effluent (Sharma et al. 2023). Towards the sustainable and an eco-economical approach for protecting the environment, green syntheses of biopolymeric metallic nanoparticles (BMNPs) are preferrable for degradation of pollutants like dyes (Emmanuel et al. 2023). These BMNPs could be fabricated using different metal/metal oxide-NPs and biopolymers like cellulose, chitosan, dextran, and starch, derived from natural sources (**Table 3)**. Nano-management in water sector using different NMs could be listed in **Figure 3**.

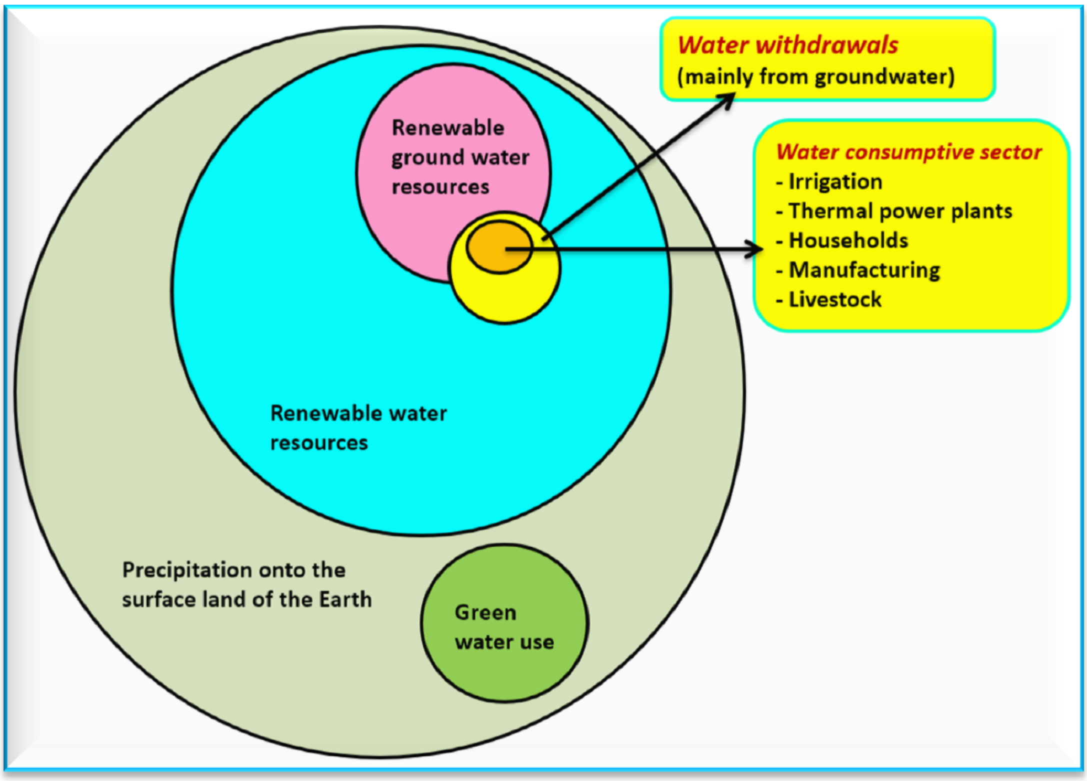

Fig. 2. Different renewable sources of water, water withdrawals, and consumption.

Table 2: Removing pollutants by using nanomaterials (NMs) from wastewater.

Pollutant kind	Nanomaterial type	MN-size	Removing rate	Reference
Reactive dyes from wastewater	ZnO – TiO_2 nano-photocatalyst	50 nm	75% efficiency of dye degradation	Haghighizadeh et al. (2023)
Levofloxacin and antibiotics	Nano-zero-valent iron and nano-copper	Both 23-32 and 21-35 nm, resp.)	Effective adsorbents by 95 and 91 % for nZVI and CuO-NPs, resp.	Hamad and El-Sesy ME (2023
Phenols in industrial wastewater	Modified nano-Zero-Valent Iron (nZVI)	45 nm	Max. removal phenol efficiency was 91%	De et al. (2023)
2,4-dichlorophenol	$CuBi_2O_4$ nano-composites	Dumbbell-like	Photocatalytic perform at 91.6% at pH =11.0	Rakshitha et al. (2023)
Dyes and pesticides	Magnetic carbon nanocomposite	30–35 nm	Max. adsorption rate or capacity was 120 mg/g	Nille et al. (2023)
Methylene blue dye	ZnS-NPs using extract *Artemisia Herba Alba*	4 nm	Degradation rate 94.09% in 180 min	Ouni et al. (2023)
Methylene blue dye	Zirconium seleno-phosphate nanocomposite	21–92 nm	Degradation efficiency was 99 %	Kaur and Jindal (2019)
Congo red dye	GO-TiO_2 – Alginate-carboxymethyl cellulose	20 nm	Degradation efficiency was 98 %	Thomas et al. (2017)
Poncaeu BS dye	Polyaniline/chitosan-Ag biopolymer	50 nm	Degradation efficiency was 100 %	Sultana et al. (2017)
Rhodamine B dye	Cellulose-Ag_2-ZnS biopolymer	6–10 nm	Degradation efficiency was 98 %	Kumar and Kumar (2019)
Acid Orange 7 dye	Chitosan ZnO + GO biopolymer	30–40 nm	Degradation efficiency was 97.5 %	Sheshmani and Ghamsari (2020)
Methyl orange dye	Chitosan SnO_2 biopolymer	15 nm	Degradation efficiency was 92%	Gupta et al. (2017)
Rhodamine B dye	Cellulose nano-crystal ZnO/CuO	91.3 nm	Degradation efficiency was 99.7%	Elfeky et al. (2020)

Table 3: List of some biopolymeric metallic nanoparticles forming by green synthesis approach.

Biopolymeric metallic nanoparticles	Metal/metal oxide precursor	Used temperature (°C)	Time (hour)	Reference
Chitosan@Cu	$CuSO_4.5H_2O$	70	12	Manikandan and Sathiyabama (2015)
Agar@Ag	$AgNO_3$	70	1	Emam and Ahmed (2019)
Agar@Au	$AuCl_3$	70	1	Emam and Ahmed (2019)
Glucan@Au	$HAuCl_4$	70	–	Sen et al. (2013)
Sodium alginate@Au	$HAuCl_4$	–	24	Li et al. (2015)
Cellulose@Pd	$PdCl_2$	80	–	Li et al. (2017)
Chitosan@Cu	$CuSO_4$	70	3	Sathiyavimal et al. (2020)
Chitosan@Guar-gum@Ag	$AgNO_3$	Ambient	1	Vanaamudan et al. (2018)
Gelatin@Ag	$AgNO_3$	–	8–10	Kamal et al. (2020)

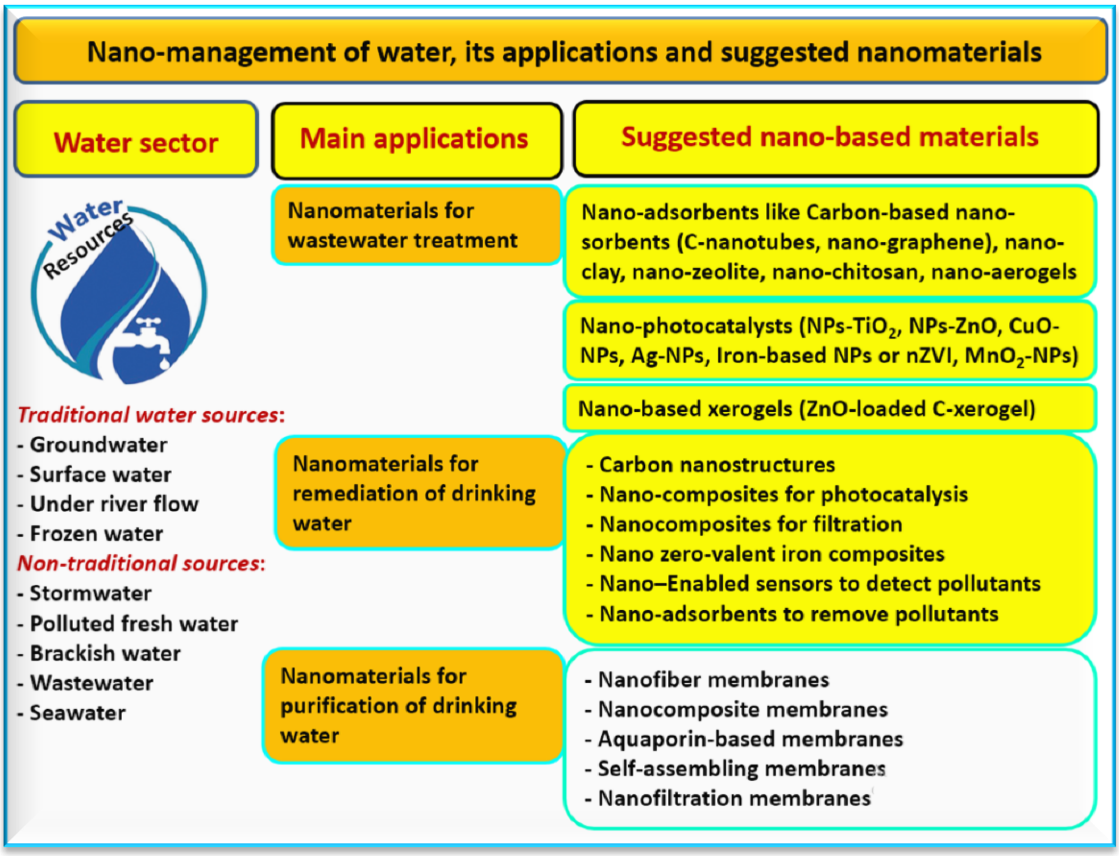

Fig. 3. List of main applications of nanomaterials in water sector for its management.

4. Nano management of energy sector

Energy is the main dynamo for human activity, and its global demand is in continuous growing. Many sources of energy that include renewable (wind, sunlight, rain, tides, waves and geothermal heat) and non- renewable forms (fossil fuels including coal or hydrocarbon fuels), as well as nuclear fuels (**Figure 4**). What are the main applications of energy? These applications may employ a wide-ranging energy landscape including theoretical understanding of novel energy materials, their synthesis characterization, and fabrication technologies with focus on the production on the commercialized level at more affordable prices (Kalyani and Dhoble 2021). The energy materials might involve the fuel cells, thermoelectric materials, photovoltaic materials, rechargeable battery materials, semiconducting materials, and a wide range of materials for impending research into existing and future energy technologies. An incredibly dynamic area can be found regarding research possibility to face different global challenges, towards more sustainable, ecofriendly, cost effectively materials for reducing carbon missing particularly during the energy generation (Kalyani and Dhoble 2021).

The development of more efficient and sustainable technologies for generating and storing energy is vital. Energy management may include control, monitoring, and optimization of the consumption of energy in order to decrease energy costs and conserve use. Nanotechnology has shown promising applications in the energy industry, which include production (Jayaprabakar et al. 2023), transforming, and storage of energy (Daneshazarian and Berardi 2023). Several nanomaterials (NMs) have applied for energy storage and conversion such as 3D self-supported amorphous NMs (Zhang et al. 2023), triboelectric nanogenerators (Wang et al. 2023), SnO_2/Ag/SnO_2 nano-coatings (Baygi 2023), nano-encapsulated phase change materials (Ghalambaz et al. 2023), nano-porous structure-based electrochemically active electrode (Malik et al. 2023), carbon nano-materials including carbon nanosheets or nanotubes or graphene (Rajeshkumar et al. 2023), $LiAlH_4$-adding nano-CeO_2 (Zhang et al. 2023), and Ni nanoparticles (Xu et al. 2023). Nano-applications for green energy are considered outstanding energy approach, which can used different NMs to produce, convert and storage energy. What would the role of NMs in energy production, storage and commercial usage? More details were presented in the following **Table 4**.

Fig. 4. Different sources of energy for our life in farm, factory, in the global level.

Table 4: Applications of nanomaterials (MNs) used for production of green energy.

Nanomaterials	Green energy application	Reference
Nano materials in general	Green hydrogen production using renewable or low-carbon energy sources	Jayaprabakar et al. (2023)
Using nanotechnology-based processing strategies	Agro-waste management by converting into sustainable energy or nano-enabled energy applications	Sonu et al. (2023)
Nano-functional materials	Applications of microfluidic fabrications of green materials in the fields of energy storage	Qi et al. (2023)
Recyclable green nano $CoWO_3$@rGO composite	Producing biodiesel from wild, uncultivated and non-edible seed as greener and sustainable energy approach	Munir et al. (2023)
Nano insulations for saving energy consumption	Green building with the nanomaterial lay-up (thickness of 0.2 cm) has the lowest fuel cost of 10 USD per m^3	Ghalandari et al. (2023)
Green synthesized cerium oxide (CeO_2) nano-additive	Green synthesized nano-additive dosed biodiesel-diesel-water emulsion blends for CI engine application	Manimaran et al. (2023)
Nanoscale solar energy absorber based on stacked bilayer nano-arrays	High-efficient ultra-broadband nanoscale solar energy absorber based on stacked bilayer nano-arrays structure for solar energy harvesting	Guo et al. (2023)
Metallic (silicon oxide) and non-metallic (rice husk) nano additives	A better combustion process brought on by the inclusion of the green additive (rice husk) is the primary reason for the rise in efficiency (13.2%)	Kumar et al. (2023)
Green synthesis of CuO-NPs using the *Bombax ceiba* plant	Biodiesel production and nano-additive to investigate diesel engine performance-emission characteristics	Arun et al. (2023)
Preparing cellulose nanofibrils for rice straw	Green and energy-efficient extraction of cellulose nano-fibrils from rice straw	Saini et al. (2022)

5. Nano management of food sector

Food industry involves the food processing, handling, packaging, preservation, safety and biosecurity, delivering the bioactive compounds, and food functioning (Singh et al. 2023). Yet, all the previous processes are considered sources for food damage, which should be managed via applying appropriate approaches like nanomaterials (**Figure 5**). By the beginning of the 20th century, food industry has gained an increasing concern to nanotechnological products with a focus on the improving food safety, shelf-life and nutrient delivery of these products through nano-functional food (Su et al. 2023). The main nanomanagement area in nano-delivery system could be achieved by delivering functional nutrients in certain forms such as nano-emulsion, nano-micelles (nano-casein micelle, and nanocomposite of green tea and proteins), nanoliposomes (by encapsulation of protein, vitamins, lipids, and antioxidants), nano-capsule (nano-capsule of vitamin E), nano-emulsion (curcumin nano-emulsion), and nano-nutrient additives (Sarangi et al. 2023; Su et al. 2023). As common subject to microbial or chemical spoilage, foodstuffs face always serious problems in food industries, including economic losses, food safety threats, and waste increment, which need a revolution in food processing (Barzegar et al. 2023), and nano-smart food packaging systems (Sarangi et al. 2023). Nanomaterials in food sector can be found in many applications such as nano-emulsions, which have several specific functions in food industry including improve texture and stability, increase bioavailability, flavoring, colorants, antioxidants, and preservative carriers (Barzegar et al. 2023).

Nanotechnology can offer a viable strategy for integrating cutting-edge technologies into a wide range of operations related to food production, fabrication, development, packaging, storage and its distribution (Biswas et al. 2022). Concerning nano-based food science, the most fundamentally sophisticated nanotechnologies using a wide range of NMs might include nano-packaging, nanocomposites, nanotubes, nanosensors, nano-capsules, liposomes, nanoemulsions, polymeric nanoparticles and nanoencapsulation (Nile et al. 2020). Applied NMs to food processing improved physicochemical qualities of food and increasing the stability and bioavailability of nutrients in food stuff. This has led to production of novel products with better food quality properties such as taste, texture, stability, and sensory properties (Hegde et al. 2022). The protection of bio-preservatives against pathogens or adverse conditions and controlling the release of the agents efficiently for preventing the food spoilage due to microbial contamination is called nano-encapsulation (Eghbal et al. 2022; Siddiqui et al. 2023). Nanoencapsulation can improve the bioavailability of ingredients in the functional food by increasing their water solubility or dispersibility in beverages and foods. This process may also exhibit good dose-dependent functionalities, mask undesired flavors or tastes to enhance shelf-life and compatibility during production, transportation, storage, and utilization of foodstuffs (Gholam Jamshidi et al. 2023).

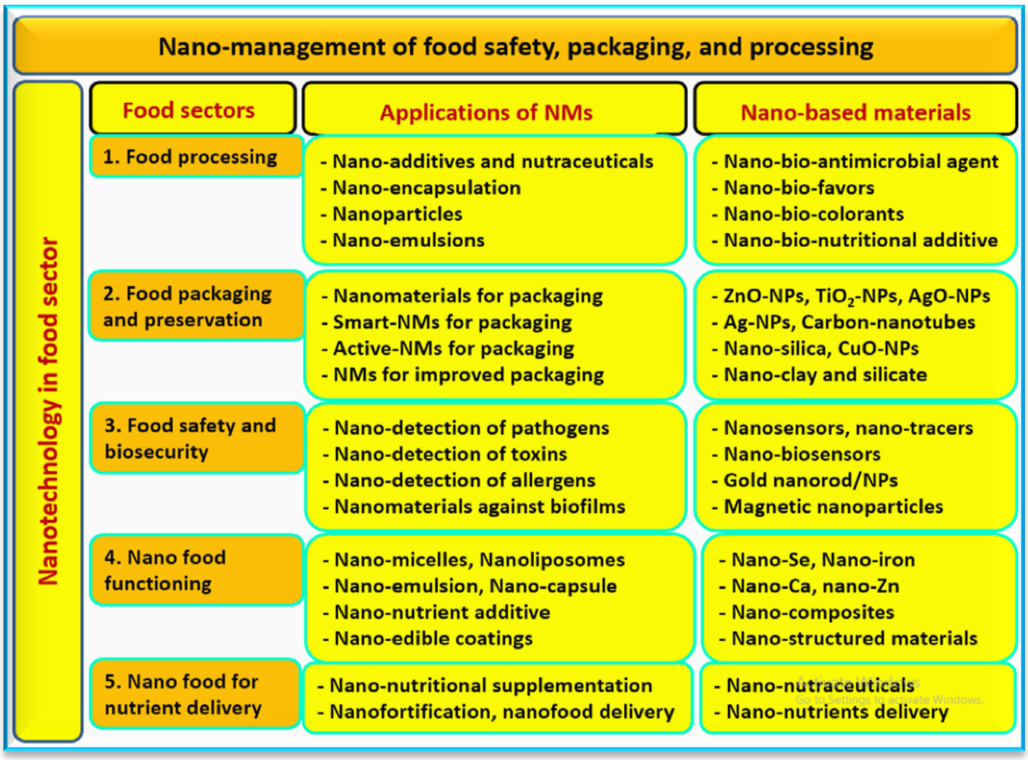

Fig. 5. Different applications of nanomaterials in food industry including different sectors.

The widespread application of NPs in different sectors and agro-ecosystems as delivery of nutrients, functional active ingredients in food packaging materials, food additives, nanopesticides, animal nano-feeds, and nanofertilizers to improve the quality, bioavailability, and performance complement or upgrade. This intensive application led to NPs migration from the environment to food increasing the exposure risk to humans (Chen et al. 2023). Several recent reports discussed the nano-toxicity in food chain (Mallia et al. 2022), cultivated plants (Kang et al. 2023), plant-soil systems (Ahmed T, et al. 2023), soil microbial communities (Ahmed A, et al. 2023), and human health and the environment (Kumah et al. 2023). During nano-food processing and packaging, several NPs or NMs might reach to human through the oral consumption of NPs-enhanced food and/or their ingestion of nanoparticles, which have migrated from nanofood packaging (**Figure 6**). According to several previous studies, ingestion of NPs has been linked to protein denaturation, stimulation of oxidative stress responses, DNA damage, as well as genomic instability, and genetic materials mutation (Biswas et al. 2022; Mallia et al. 2022).

6. Water-Energy-Food Nexus under climate change

The greatest challenges facing our world are mainly linked with the water, energy and food nexus. This enforced several Labs all over the word for searching of new and alternative approaches to overcome these previous challenges under climate change such as Nano-Food Lab (Debrecen University), which has a promising research plan working on the WEF nexus. This program involved study on nano-nutrients for increasing carbon sequestration (El-Ramady et al. 2021), nano-management of agro-wastes (El-Ramady et al. 2020; 2022a), and nano-restoration of soil fertility (El-Ramady et al. 2022b, c). These studies also focused on the mushrooms as healthy food (El-Ramady et al. 2022d; Llanaj et al. 2023; Töros et al. 2023), and for green synthesis of nanoparticles (Elsakhawy et al. 2022). The nano-mitigation of climate change also has a great concern in our Lab, which was translated into a publication on climate change such as Abdalla et al. (2022), nano-enabled agriculture (Sári et al. 2023), and soil–water–climate change nexus (Koriem et al. 2022). Nanotechnology has proposed many sustainable strategies to several environmental stresses or problems such as greenhouse gas emission, wastewater treatment, fuel crisis, remediation of various pollutants, water and food crises, and detecting phytopathogens (**Figure 7**).

Hence, nanotechnology can produce many approaches for protecting the environment and mitigating climate change (Chausali et al. 2023). Climate change has a serious number of human health issues (especially for cold regions like Europe), where higher temperature may induce infectious diseases vectors, allergic pollens, mortality, cardio-respiratory diseases, malnutrition or poor nutrition, and pressures on mental health (Teasdale and Panegyres 2023). Climate change affects human health *via* initiating and/or increasing intensities of disasters (e.g., suboptimal temperature, droughts, floods, wildfires, and storms) and demographic, socioeconomic, and environmental pathways (Zhao et al. 2022). This reflects many global features on our planet which can be noticed in **Figure 8**. These health issues were confirmed in different regions such as River Basin in Jilin Province, China (Ren et al. 2022), Western Australia (Teasdale and Panegyres 2023), South America (Palmeiro-Silva et al. 2023), Caribbean region (Cloos et al. 2023), Eastern Mediterranean and Middle East (Neira et al. 2023), and central Arizona (Guan and Mascaro 2023).

Several studies reported the strong relationship between water-energy-food (WEF) nexus and climate change depending on different topics such as the role of water circularity in WEF nexus under mitigation of climate change (Samberger 2022), understanding implications of socio-economic development and climate change under WEF nexus (Han et al. 2022), evaluation the impact of climate change on carbon emissions in protected farming systems under WEF-carbon nexus (Yoon et al. 2022), the importance of this relation to decision-making processes (Herrera-Franco et al. 2023), evaluation the agro-adaptations to climate change under WEF nexus (Wu et al. 2023), impacts of WEF on bioeconomy and future climate change (Ngammuangtueng et al. 2023), and the role climate action under WEF nexus for environmental management (Lalawmpuii and Rai 2023).

Definitely, several open questions are still needed to be answered concerning the applying of NMs for the three sectors. Regarding water sector, it could summarize in the following questions, as reported by Singh and Gurjar (2023):

1- Are NMs efficient, cost-effective, and have a large surface area for removing pollutants from water?

2- Can it meet WHO guidelines for drinking water?

3- Will it be a part of our wastewater system as soon as cost and eco-friendly methods are developed?

4- Can it be improved through particle modifications?

5- Are NMs require less space, and produce fewer byproducts as compared to conventional methods?

6- Are NMs ready for market use due to environmental challenges and cost-effectiveness or not yet?

7- Can NMs minimize energy requirements, chemical consumption, and waste residuals during water treatment?

More questions can be listed as follows:

What are water storage options for farmers?

How can water re-use reduce food-energy trade-off?

What ways of operating dams sustain wetland fisheries?
What are the technologies of energy efficient water-treatment?
What technologies make irrigation make water efficient?
How does watershed management help hydropower?

7. Conclusions

Our planet faces great challenges to save the essential requirements for the human life especially water, energy and food. These requirements were increased under the global threat of climate change and incredible increase in global population. Day by day, the universe is seeking for new and sustainable approaches for mitigating the changes in global climate. The nano-approach is a promising strategy that can solve many environmental issues concerning to human health, clean water, sustainable energy and healthy food especially under global climate changes. Nano-management for many problems in resources of WEF nexus were confirmed by several studies, but this role under climate change still needs more investigations. Due to the very complex interrelationship among climate change, WEF nexus and nanotechnology, more studies are needed for drawing the future strategies to mitigate climate change. The main target of further works is linked to the concept of "one health".

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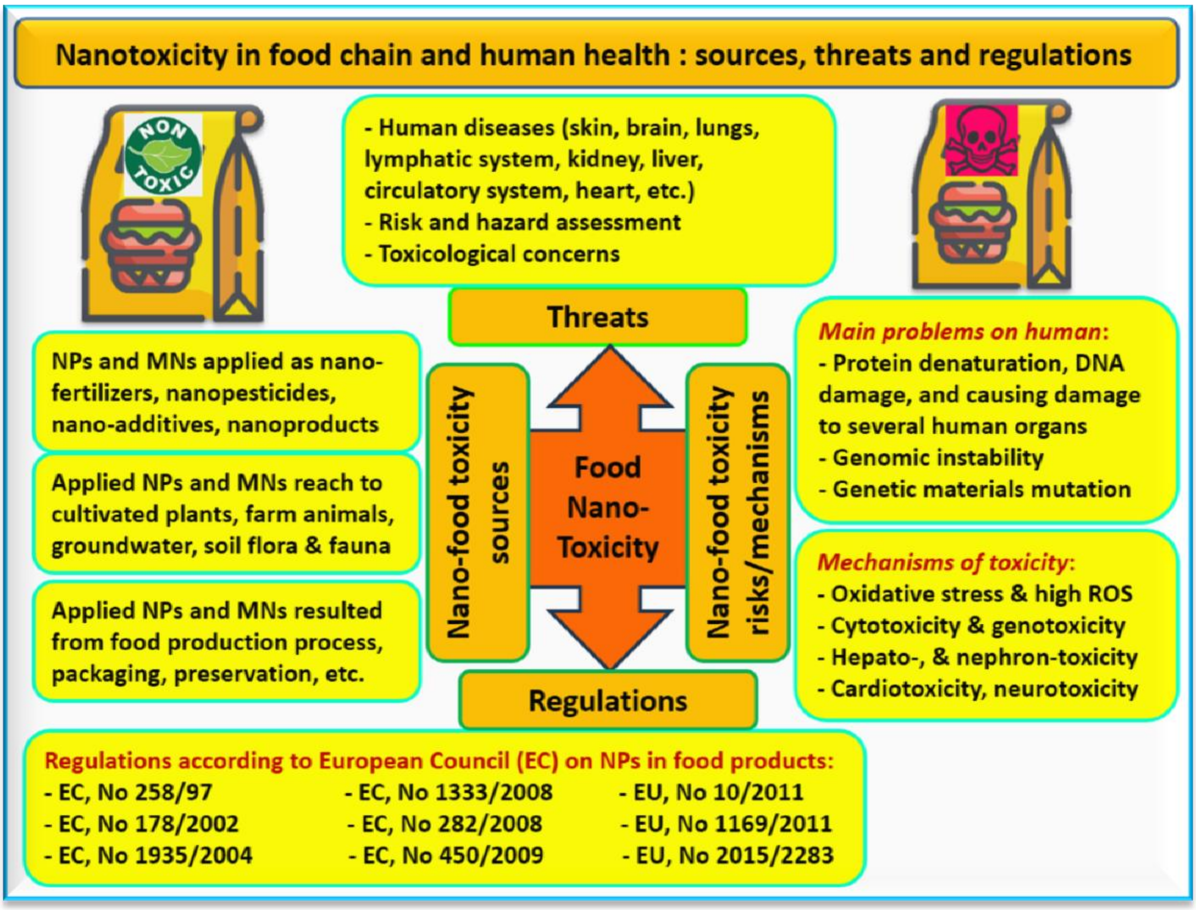

Fig. 6. The pathway of nanomaterials during the food processing reaching to the human with focus on nanotoxicity. The accumulation of applied nanoparticles by time may create this toxicity on soil, plant, microbes and human health.

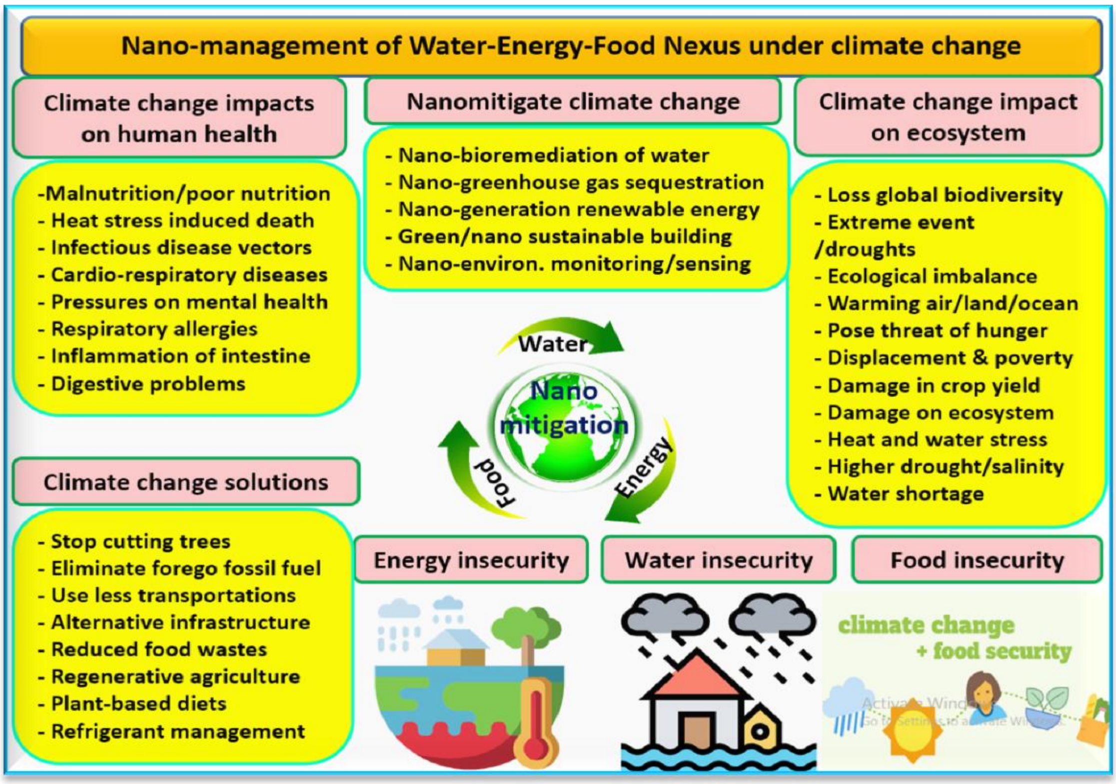

Fig. 7. The possible nano-approaches to mitigate climate change under water, energy, and food nexus. The impacts of climate change on human health and ecosystem, suggested solutions as well as the nano-mitigation to climate change.

Fig. 8. Some cartoon photos on the status of our planet under climate change disasters. Sources: https://za.pinterest.com/pin/682365781060219886/ accessed on 02.09.2023

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