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A Review of Environmental, Social and Governance Frameworks in Sustainable Disposal of Waste from Renewable Energy Resources

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Abstract: The shift to renewable energy sources is essential for mitigating climate change, but it poses fresh challenges for environmentally responsible waste management. This article reviews and investigates the complex problems associated with the disposal of renewable energy components from an environmental, social, and governance (ESG) perspective. The article further highlights the need for thorough oversight and careful management of various components due to the environmental concerns associated with their disposal as they frequently contain hazardous elements. The social effects on communities impacted by disposal procedures are also explored, and the importance of fair distribution of benefits is emphasized. Transparency, accountability, and stakeholder involvement are bolstered by effective governance, which is a central theme of this discussion that draws on ESG concepts. Successful ESG-integrated disposal plans are demonstrated by industry case studies. Possible hindrances in sustainable disposal are also highlighted with firm suggestions on way-forward, which include technical innovation and global collaboration. The study underlines the irreplaceable role played by ESG in guiding responsible waste management toward a sustainable, green energy future.

***Keywords*:** *Renewable energy, Governance, Solar, Photovoltaics, Environmental Sustainability, Waste Management.*

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1.0 Introduction

The state of the global energy scene is extremely important. The need to switch to ecologically friendly and sustainable energy sources is more important than ever as the threat of climate change grows[1]. Renewable energy technologies have become highly instrumental in the fight against climate change in this period of unparalleled environmental difficulties[2]. They provide a means of cutting greenhouse gas emissions and laying the groundwork for a sustainable future since they can be used to harness plentiful, clean energy sources like solar, wind, and hydropower. Renewable energy sources draw on the plentiful, replenishable resources found in nature, as opposed to conventional fossil fuels, which diminish finite resources and increase greenhouse gas emissions[3]. A fundamental change in how we think about the production and use of energy is brought about by renewable energy technology [4] [5]. Renewable energy technologies mark a fundamental change in how we think about producing and using energy. A wide range of renewable energy technologies exist, along with their various applications and the revolutionary effects they have on the world's energy landscapes[6], [7]. A more ecologically conscious and sustainable energy paradigm is being ushered in by a number of technologies, including geothermal power plants, hydroelectric dams, and photovoltaic solar panels. These technologies have the potential to transform the energy industry and spark a more resilient, sustainable, and prosperous future for the world through innovation and broad adoption[8][9]. In order to mitigate climate change, which is a crisis that jeopardizes the ecological balance of our planet and the welfare of present and future generations, renewable energy solutions are essential. When it comes to solving some of the most important global issues of our day, renewable energy solutions are extremely important[10]. Growing amounts of greenhouse gases are being released into the atmosphere of the Earth as a result of the burning of fossil fuels for transportation, industrial activities, and the production of electricity. This has caused the oceans to become more acidic and resulted in rising global temperatures. Negligence has an adverse effect on ecosystems, human livelihoods, and the availability of food [11].

Renewable energy sources provide a lifeline as a cleaner, more sustainable option to conventional energy derived from fossil fuels. Through the capture of energy from renewable sources like sunshine, wind, and flowing water, these technologies help to minimize carbon emissions, reduce air pollution, and lessen our reliance on finite fossil fuel supplies[12]. They offer a workable way to slow down global warming and modify the planet's climate trajectory[13]. Reducing dependence on imported fossil fuels and diversifying energy sources might help countries improve their energy security and ease geopolitical tensions around energy resources [14]. Investing in renewable energy technologies reduces costs and promotes innovation. This supports the development of increasingly cost-effective and efficient solutions and promotes healthy competition in the energy market [15]. The renewable energy industry has proven that it is capable of promoting economic expansion. Jobs are created as a result of investments in renewable energy projects in manufacturing, research and development, and facility construction and operation. Renewable energy sources are essentially limitless, in contrast to finite fossil fuel supplies. The sun, wind, water, and the heat from the earth all serve as a plentiful and never-ending source of energy. Renewable energy technologies can offer a scalable and economical option for areas lacking access to cheap and dependable power. Remote locations may be able to receive electricity thanks to off-grid systems, especially those run by solar and wind power[16]. In contrast to massive hydropower dams, the environmental impact of many renewable technologies is negligible. Installations of solar and wind power, for instance, require very little land and do not interfere with ecosystems or wildlife habitats. Small-scale wind turbines and rooftop solar panels are examples of distributed renewable energy technologies that can improve grid resilience by decentralizing electricity generation[17]. As a result, there is less susceptibility to interruptions brought on by severe weather or other situations. Numerous renewable technologies have rather minimal environmental effects, in contrast to massive hydroelectric projects. Examples of renewable energy sources that do

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not disturb ecosystems or wildlife habitats are solar and wind farms, which have very low requirements for land use.[18]

The advantages of renewable energy technologies for the environment are however not without complexity. Although they greatly lower emissions while they are in operation, managing them after they reach the end of their useful life poses unique issues. To guarantee the sustainability of these technologies throughout their life cycles, the disposal of renewable energy components, such as solar panels, wind turbine blades, and energy storage devices, needs to be taken care of.

The necessity of addressing the environmental and social issues related to waste disposal from sources of renewable energy is the rationale behind this study, which focuses on incorporating ESG frameworks for all-encompassing and sustainable solutions. Some of the significant aspects of this study include.

- Integration of core principles of ESG: This research investigates how waste produced from renewable energy sources might be disposed of while considering ESG frameworks. For waste management procedures to be in line with more general sustainability objectives, integration is essential.
- Renewably Sourced Energy through Sustainable Waste Management: The waste that is produced in tandem with the global transition to renewable energy sources—such as solar panels and wind turbine blades—presents special difficulties. This study tackles the requirement for environmentally responsible waste management techniques that successfully reduce the negative effects of renewable energy technology on the environment.
- Assessment of Environmental Impact: This study explores how waste disposal practices related to renewable energy technology affect the environment. To limit harm and improve the long-term viability of renewable energy sources, measures for minimizing their effects on the environment must be developed.
- Implications to communities and the society: In ESG frameworks, the social and communal dimensions of sustainability are highlighted. This study evaluates the social effects of waste disposal techniques, taking community involvement, safety, and health into account. This more expansive viewpoint is essential for encouraging socially conscious behavior.
- Regulatory compliance and governance: The management of waste is significantly influenced by governance principles. The regulatory frameworks and governance structures controlling the disposal of waste from renewable energy sources may be examined in the study. Responsible waste management techniques require an understanding of these standards and adherence to them.
- Identifying best practices: The study pinpoints and assess best practices for ESG-compliant waste management utilizing renewable energy sources. These observations can be very helpful in guiding businesses, decision-makers, and practitioners toward the adoption of sustainable waste management practices.
- Corporate Ethics and Reputation: Compliance with ESG guidelines for waste disposal is not just mandated by law but also an essential aspect of corporate social responsibility for businesses operating in the renewable energy space. The outcomes of this study provide insights into how businesses can improve their ESG performance, which would benefit their stakeholder interactions and reputation.
- Policy Recommendations: The study could result in the creation of policy suggestions for governing bodies and oversight organizations. These suggestions can direct the creation of all-encompassing waste management regulations that support environmentally friendly practices in the renewable energy industry.

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Summarily, this study contributes valuably by expanding the scope of knowledge, offering useful perspectives, and directing players in the renewable energy industry toward more environmentally friendly and socially conscious methods of disposing of waste.

2.0 Environmental impact of end-of-life renewable energy technologies

The amount of waste produced by retired systems and components is increasing along with the rapid adoption of renewable energy technology. These materials pose particular environmental issues when disposed of, even though they are linked to decreased emissions during their operational phase. As an illustration, although solar panels are praised for producing clean energy, they also include rare earth metals and other potentially dangerous components that need to be disposed of properly. Similar difficulties may arise with recycling and environmentally friendly disposal of wind turbine blades, which are frequently made of composite materials. It is important to consider the effects incorrect disposal has on the ecosystem. Ineffective waste management can have a negative impact on nearby ecosystems, pollute the land and water, and disturb habitats. In addition, it raises moral questions about how equally the effects of the trash should be distributed, since vulnerable populations may suffer disproportionately from inappropriate waste disposal methods[19]– [23]. Thus, in order to minimize the ecological impact associated with the decommissioning of renewable energy technology, the section addresses the adoption of responsible disposal procedures, recycling programs, and adherence to regulatory criteria.

The idea of Environmental, Social, and Governance (ESG), arises as a guide to negotiate these environmental challenges and create a framework for responsible garbage disposal. As shown in Figure 1, ESG guidelines offer a comprehensive method for assessing the ethical and sustainable aspects of a company's operations, which includes waste management procedures[24], [25]. Beyond environmental factors, ESG also includes social factors and governance practices that affect an organization's operations and decision-making. ESG principles emphasize the significance of social consequences on communities, ecologically responsible waste management, and governance structures that give priority to long-term results in the context of renewable energy technology[26]. ESG provides a methodical way to evaluate and enhance waste management plans regarding elements of renewable energy. Figure 1 highlights the significance of responsibility, transparency, and stakeholder involvement, laying the foundation for an all-encompassing and responsible strategy for various renewable energy technologies' end-of-life phase [27].

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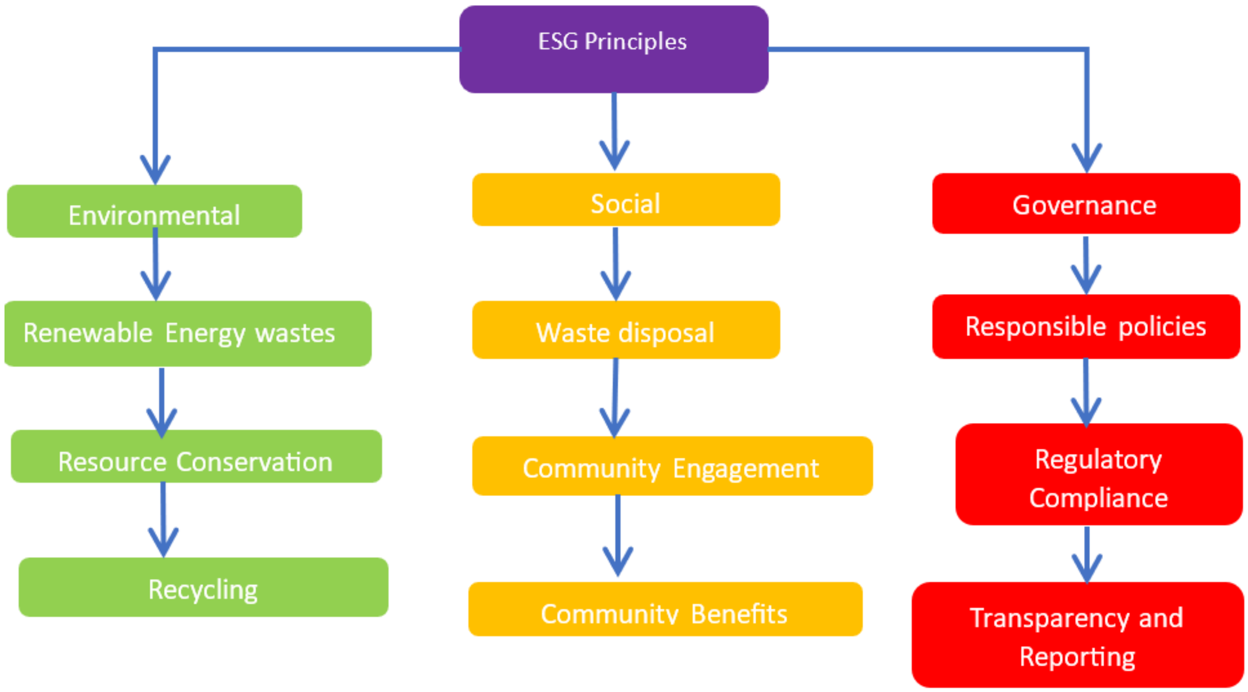

Figure 1. Relationship between ESG (Environmental, Social, and Governance) and renewable waste disposal

The nuances of ESG are explored in this study with respect to the environmentally responsible removal of components of renewable energy in the pages that follow. In addition to providing case studies and best practices, we examine the environmental, social, and governance aspects that influence responsible waste management. The essay explains how important ESG is to building a just and sustainable future for renewable energy technology, because the promise of a greener, cleaner world depends on how end-of-life waste is disposed of [28]–[30].

2.1 Environmental considerations in the disposal of renewable energy technologies

The use of renewable energy technologies is a promising development in the worldwide endeavor to combat climate change. Over the course of their useful lives, these technologies dramatically lower greenhouse gas emissions by utilizing energy from renewable resources like sunshine, wind, and water. The environmental issues surrounding the elimination of renewable energy technologies once their useful lives are done are, nevertheless, sometimes disregarded as the world adopts renewable energy at a faster rate. We will examine the environmental issues surrounding the elimination of these technologies in this discourse, stressing the significance of resource conservation, waste management, and responsible recycling [31]. Addressing climate change and securing an energy future that is sustainable depends on the expansion of the renewable energy sector. It is imperative to take into account the complete lifespan of these technologies, encompassing their disposal as well. In order to maintain renewable energy's sustainability from an environmental and financial standpoint, proactive approaches to waste disposal, recycling, and conserving resources are essential. An authentically green and sustainable energy transition depends on an ethical end-of-life management of renewable energy technology, which is also an environmental concern [32]. Various considerations are discussed as follows.

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A. Challenges in disposal

There is a limited lifespan for each component in all forms of renewable energy technology, including energy storage systems, wind turbines, and solar panels. Decommissioning or replacement of these parts are eventually required. To prevent adverse environmental impacts, proper management of this material's disposal is necessary. For instance, dangerous materials like cadmium and lead are included in solar panels, despite their reputation for producing clean energy. These substances pose hazards to human health and ecosystems if they are not handled properly and leak into the environment [33]. In a similar vein, recycling wind turbine blades—which are frequently made of composite materials—can be difficult. These products could wind up in landfills, adding to the volume of rubbish and possibly contaminating it. Systems for storing energy, which are essential for maintaining grid stability and integrating intermittent renewable energy sources, may include parts that pose a risk to the environment. This is potentially hazardous materials contained in the batteries.

B. Recycling as a Solution

Recycling offers a viable way to lessen the negative environmental effects of disposing of renewable energy equipment. It is now feasible to retrieve important components from these devices because to advancements in recycling procedures. Recycling solar panels, for example, can salvage valuable metals and lessen the need to extract raw materials, thereby reducing environmental impact and preserving resources. When it comes to wind turbine blades, scientists are looking for inventive ways to reuse these materials, from building with them to creating new materials with other uses. Even though these initiatives remain in their initial phases, they show a rising dedication to lowering waste and its negative effects on the environment [34].

C. Waste Management

Another essential element of ethical disposal is effective waste management. To avoid contaminating the environment, tight containment procedures, frequent monitoring, and the safe disposal of potentially hazardous material in landfills are crucial. The impact of trash from renewable energy sources is kept restricted and localized thanks to good waste management techniques[27].

D. Resource Conservation

Resource conservation is one of sustainability's core ideas. Effective recycling procedures and conscientious waste management techniques reduce environmental hazards while simultaneously preserving important resources. The renewable energy industry may lessen its impact on the environment and cut expenses related to obtaining raw materials by decreasing the requirement for raw material extraction. The circular economy's guiding principles are furthered by resource conservation throughout the disposal phase, which is consistent with larger sustainability aims[31].

Attaining an energy future that is sustainable and reducing climate change depend on the growth of the renewable energy sector. But it's crucial to take into account every stage of these technologies' lifecycle, including disposal. For renewable energy to continue to be economically and environmentally viable, proactive approaches to resource conservation, waste management, and recycling is essential. Additionally, an environmental issue, effective end-of-life handling of renewable energy technology is essential to a truly green and environmentally friendly energy shift[25].

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2.2 Review of related works

Following the world's shift to renewable energy, issues regarding the environmental and social effects of disposing of waste from renewable energy technology have surfaced. To investigate how ESG concepts might be integrated into the sustainable disposal of waste from renewable energy resources, this literature review critically evaluates previous research and frameworks. This section therefore reviews existing studies on ESG frameworks to provide a better understanding on their impact on renewable energy wastes disposal. The swift growth of sustainable energy technologies, such as wind, solar, and hydropower, has drawn more attention to the end-of-life issues these technologies present. Studies by Yeom et al. [35] and Mozhiarasi [36] emphasize the possible repercussions on the environment and society of inappropriate waste disposal methods within the renewable energy industry. Applying ESG frameworks to corporate sustainability is a crucial topic for this study's discussion. Escrig-Olmedo et al. [37] maintains that robustness and long-term performance in business operations depend on the integration of ESG principles. The framework for comprehending how ESG can be modified to handle waste disposal issues unique to the renewable energy environment is thus established.

Comprehensive Environmental Impact Assessments (EIAs) are crucial for renewable energy projects, as demonstrated in studies, such as [38] and [39]. The ecological consequences of waste disposal practices are also addressed by the assessments, in addition to the evaluation of the environmental implications of energy production. The importance of social factors in disposal of waste is growing. Arena et al. [40] and Lee et al. [41] emphasize the necessity of evaluating the social ramifications of disposing of waste from renewable energy, including matters pertaining to stakeholder participation, safety, and community health. The significance of a socially conscious approach to waste management is emphasized by the two research articles. Important components of the sustainability equation are the legal frameworks and governance structures that control the disposal of garbage. Elele [42] and Oyedotun [43]explore the legislative gaps and governance issues that could prevent efficient waste management. Strong governance systems that are in line with ESG principles are essential, as these publications highlight. A major focus of the review of literature is the determination of optimal procedures for disposing waste. Innovative waste management techniques that support sustainability objectives are discussed by Sheoran [44] and Hoyer [45]. For companies looking to improve their disposal procedures, these studies provide useful standards. t's critical to comprehend how ESG principles are included into the whole renewable energy supply chain. The need for a comprehensive strategy that takes into account production, operating, and end-of-life concerns is emphasized in Whitelock [46]'s exploration of how ESG factors might be incorporated into the supply chain. An organization's reputation is impacted by its corporate responsibility for waste disposal. Wood [47] discusses the relationship between good business reputation and ethical waste management techniques are related in the renewable energy industry. These pieces demonstrate how brand image and ESG practices are related. Table 1 provides a review of relevant studies on ESG frameworks in the renewable energy sector.

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Table 1. Review of related works and its findings

Author	Year	Aim	Findings/Conclusion
Dhanya et al. [48]	2020	To achieve sustainable development of bioenergy through the efficient enforcement of zero waste discharge policies.	A sustainable bioenergy industry addresses the difficult issue of waste disposal of renewable energy resources in the face of climate change. It does this by improving fuel security, stepping up organic waste conversion techniques to bioenergy, particularly biogas and biohydrogen generation.
Amin et al. [49]	2023	To analyze the major sources of solid waste generation and potential waste management strategies, including thermal treatment (gasification, pyrolysis, and incineration) and biological landfills.	Individual country-specific solutions for municipal solid waste management are highly recommended for energy generation that have the least negative environmental impact possible.
Munir et al. [50]	2023	To increase understanding of the potential for food waste to produce hydrochar, a clean fuel that can replace traditional non-renewable energy sources in the steel industry.	Significant greenhouse gas emissions are produced during the energy-intensive process involved in steel production, which exacerbates climate change and environmental damage. The utilization of fuels obtained from food waste offers a viable substitute for conventional fossil fuels. In addition to solving the problem of trash disposal, turning food waste into useful energy resources lowers carbon emissions and the industry's dependency on finite energy sources, supporting the ideas of the circular economy and sustainable development.
S. Cho et al [51]	2023	To decrease the spread of microplastics by combating the widespread, unregulated usage and careless disposal of products made of plastic.	Waste from microplastics can be converted into electrical energy by utilizing the inherent triboelectric characteristic of microplastics.
Chagunda et al. [52]	2023	To assess the viability of waste-to-energy (WtE) initiatives that provide off-grid communities with access to electricity by measuring waste chain components and doing field research, in addition to producing primary data sets through quantitative study design.	The amount, classes, moisture content, calorific values, and technologies employed are among the variables that impact the energy recovery process from Municipal Solid Waste (MSW). These variables are critical in determining the sustainability of WtE projects in comparison to other waste treatment projects, as well as the choice of the appropriate waste treatment and technology for waste treatment. Also, the majority of waste classes are appropriate for WtE generation in terms of moisture content and calorific values.

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R. Bera et al. [53]	2023	Use the Safe and Sustainable 'Clean Food' (CF) model to demonstrate how renewable sources help the system resources regenerate and restore themselves to enhance the Circular Economy (CE) in Agriculture.	When the model was assessed in light of all the fundamentals of circular agriculture, it became clear that it had the potential to increase crop yield by up to 19.5% while lowering or doing away with non-renewable inputs like chemical pesticides and fertilizers, which reduced the likelihood of residues of pesticides in food (vegetables) by roughly 93%. Soil quality was increased by up to 27% through resource recycling through the bioconversion of MSW and landfill trash into safe compost. Most notably, the CF Model delivered the essence of CE in agriculture by improving everyone's access to safe and nutritious food while decoupling economic development from the linear patterns of finite and non-renewable extraction, use, and disposal of resources. This was demonstrated by the GHG elimination of 6.4 to 11.7 kg CO2-eq / kg food production, 64% increase in productivity of energy, 16.7% increase in employment, and roughly 19.7% increase in gross income.
Burra et al. [54]	2023	To demonstrate the need for the synergistic integration of gypsum waste from the construction and demolition (C&D) industry as a sustainable disposal technique in order to efficiently recover resources and control energy	Enhanced syngas yield and homogeneity, as well as improved operating conditions from the gypsum interaction with MSW, were demonstrated in the results, this may aid in the advancement of gypsum waste incorporation.
Naviglio et al. [55]	2022	To show how wastes from oranges to produce value-added nutritional products in order to reduce the amount of waste to be disposed in the agro-industrial sector	The study shows how hydroalcoholic extraction of orange peels from industrial processing waste, yields an extract rich in essential oils that can be used in the food industry to make liqueurs and/or fragrances, as well as in the cosmetic and pharmaceutical industries.The residue obtained is an important commodity rich in dietary fiber with applications in the pharmaceutical and nutraceutical industries. Additionally, the same chemical has agricultural applications as fertilizer. Given this, waste from the processing of citrus fruits can be viewed as a renewable and sustainable energy source.
H.Hosseinzadeh-Bandbafha [56]		To demonstrate how the assessment of the environmental sustainability of Waste Cooking Oil (WCO) biodiesel production in comparison to diesel and first-generation biodiesel can be	Even though LCA's environmental assessment of biodiesel production is well-established, there are still a number of issues and limitations. In the similar studies, system limits are generally well-defined. Nevertheless, waste management has been

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		conducted using a highly effective tool called life cycle assessment (LCA).	disregarded in several studies; for instance, the analysis typically excludes the disposal of soap and other solid residues. Furthermore, as this waste stream could be a raw material for various other applications, the "zero-burden assumption" used to WCO (as biodiesel feedstock) in the published literature might not be a fair assumption. For the existing and in-development technologies utilized in WCO biodiesel production, inadequate data at the inventory level, particularly information pertaining to the creation of innovative catalysts (including enzymes) and materials used for product purification, is also a problem. As a result, the goal of future research should be to reduce the uncertainties that have been raised during this effort. Moreover, by utilizing cutting-edge methods like hydrodynamic cavitation reactors, incorporating additional renewable energy sources, and utilizing green catalysts during the WCO biodiesel production and combustion stages, efforts should be made to evaluate the environmental effects of WCO biodiesel production systems.
Ranjetha et al. [57]	2022	To demonstrate the utilization of locally accessible industrial and agricultural waste and by-products, such as steel slag aggregate (SSA), manufactured sand (M-sand), palm oil clinker (POC), and fuel ash (POFA), for the creation and building of environmentally sustainable low-cost homes.	The adoption of green technologies and the incorporation of waste by-products into concrete were shown to have many benefits. Revisions to concrete mixes utilizing waste product substitutes would help reduce environmental issues, the negative consequences of incorrect waste disposal, the dependency on non-renewable materials, and encourage the use of sustainable construction.

2.3 Social Aspects of End-of-Life Waste Disposal for Renewable Energy Technologies

Future clean energy as well as environmental sustainability are promised by the development of renewable energy technology. However, as these technologies get closer to the end of their useful lives, important social issues of waste management and disposal come up. In addition to environmental issues, there are ramifications for laborers, communities, and larger social structures [58]. First are community impacts, there is always a community impact when garbage disposal or recycling facilities are located. These sites' existence frequently elicits conflicting emotions. On the one hand, they may present chances for employment and local income. However, they may also pose a risk to one's health and safety. For instance, the process of recycling solar panels, while essential, may involve the release of hazardous materials. If not properly managed, these materials could pose risks to local water supplies or air quality. Furthermore, the transportation of waste to these sites can increase traffic, noise, and potentially lead to accidents. Additionally, these dumping sites are frequently located near underprivileged or marginalized groups, which may lack the means or political clout to oppose them. This brings up issues related to environmental justice: Are certain areas

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unfairly burdened more than others by the expansion of renewable energy?[59], [60]. Another critical social factor are the labour considerations; adequate precautions must be provided for workers in the waste management industry, particularly for those handling potentially harmful products from renewable technology. This includes labor rights issues like fair compensation, suitable hours of work, and the ability to organize, in addition to physical safeguards like the proper equipment and training. Waste management can give rise to unofficial or even unlawful labor practices in various areas. It is crucial to make sure that the renewable energy sector neither causes nor exacerbates these problems. The workers who enable the industry's pursuit of sustainability should not bear the cost of that effort[61]. In addition to aforementioned is Equitable Benefits and Community Engagement. The end-of-life disposing of renewable energy sources presents potential as well as obstacles, particularly in the area of community benefits. Well-managed disposal facilities can develop into local employment hotspots, bringing money and jobs to otherwise economically struggling areas. Ensuring equitable distribution of these benefits and giving communities a say in the development and management of projects are crucial. Public hearings, community benefit agreements, and other means of participation can help achieve this. For example, the money collected from the disposal of waste might be reinvested in regional initiatives like infrastructure, healthcare, or education. Additionally, outreach and education initiatives can be launched to make sure that the community's citizens are aware of the activities occurring nearby, the possible hazards, and the precautions being taken to lessen those risks[59].

2.4 Governance and Policy Implications

Effective policies and efficient governance are essential for managing the waste produced by renewable energy technologies at the end of their useful lives. This section examines the issue's governance and regulatory framework, emphasizes the significance of Environmental, Social, and Governance (ESG) concepts, evaluates the present policies, and makes recommendations for future developments[61]. In terms of governance and policy implications the following factors comes to play. Governance and regulations using resilient framework is required for the management and disposal of waste from renewable energy sources. To guarantee environmental preservation, public health, and safety, waste management procedures must be supervised by regulatory organizations and government agencies. Environmental impact studies, trash classification, permitting procedures, and zoning laws are all part of this governance and regulation. In the same vein, the handling and destruction of waste generated from renewable energy sources require a robust governance system. Government agencies and regulatory bodies need to oversee waste management practices in order to ensure public health, safety, and environmental preservation. This governance includes zoning rules, waste classification, environmental impact evaluations, and permitting processes. Another component is thorough permitting procedures, which is essential for evaluating the environmental effects of garbage disposal locations. Thorough environmental impact assessments need to be carried out in order to determine potential benefits and dangers. A complete understanding of the effects that trash disposal has on nearby ecosystems and populations should be the basis for granting permits. The role of governmental policies is further stressed to classification of wastes. The toxicity and ecological impact of waste produced by renewable energy methods might differ. To ascertain the needs for treatment, transportation, and disposal, appropriate waste classification is crucial. By separating hazardous trash from non-hazardous waste, this classification helps to ensure that the right disposal techniques are applied.

The implication of government policies is driven by principles and its development procedures. Policies concerning the disposal of waste from renewable energy sources are heavily influenced by Environmental, Social, and Governance (ESG) principles. Accountability, transparency, and ethical issues in decision-making processes are highlighted by ESG principles. The guidelines promote openness in waste management procedures. Clear reporting of trash

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generation, disposal techniques, and environmental effect assessments should be mandated by policy. Stakeholders are able to evaluate the social and environmental effects of waste management related to renewable energy because of this transparency. Viewing policies from accountability perspectives, waste management policies should clearly define who is responsible for what. It is the responsibility of stakeholders — government organizations, waste management businesses, and providers of renewable energy—to ensure that waste disposal practices comply with ESG guidelines. Legal repercussions for non-compliance, fines, and penalties are examples of accountability methods as well as Ethical Considerations. ESG principles place a strong emphasis on moral issues including equity, justice, and community involvement. Policies ought to support moral waste management techniques that put the health of the impacted communities and employees first. The equal distribution of the advantages of waste management is thus a matter of ethics.

Assessing how well-aligned current waste management policies are with ESG principles and how well they can reduce their negative effects on the environment and society can help determine how effective they are. Possible areas for policy improvement include but not limited to Community Involvement*:* Policies ought to require community involvement and participation in garbage disposal decision-making processes. By interacting with the community, you can make sure that their issues are taken care of and that the advantages are shared fairly. In other words, companies that produce renewable energy may be offered financial incentives by policy frameworks to invest in environmentally friendly waste management techniques. This may promote the creation of cutting-edge recycling and repurposing technology**.** Monitoring and Reporting by tightening up the standards for monitoring and reporting can lead to a more thorough comprehension of how waste disposal affects society and the environment. Regular reporting and assessments should be required by policy to guarantee adherence to ESG guidelines. Albeit, policies can support the development of technology for recycling and trash reduction but a more environmentally friendly approach to trash management may result from fostering innovation. The management of end-of-life waste from energy generated from renewable sources depends critically on efficient governance and well-structured legislation, assessment and improvement. ESG principles emphasize accountability, transparency, and ethical issues and offer a framework for developing policies. Waste disposal can comply with ESG principles by evaluating existing policies and implementing the required changes, guaranteeing social justice, environmental preservation, and a transition to sustainable energy.

3.0 Vital Role of ESG Principles

Disposing the end-of-life waste for renewable energy technology, companies and governments can use ESG principles as a compass to steer them toward socially and ecologically acceptable practices. These guidelines place a strong emphasis on the value of accountability, openness, and stakeholder involvement—all essential components of guaranteeing a sustainable future. ESG guidelines offer a framework for morally and responsibly disposing of garbage as the globe works to create a greener and more environmentally friendly energy landscape. Governments as well as organizations can achieve governance excellence when handling waste from renewable energy sources, promote social fairness, and lessen their impact on the environment by following these principles. Key steps to build the capacity to recycle renewable energy waste as part of circular decarbonization is presented in Figure 2. This framework follows a circular decarbonization principles. The procedures illustrated in figure 2 seek to create a systematic way to recycle waste from renewable energy sources. The environmental impact of renewable energy technology can be reduced while maintaining compliance with environmental, social, and governance (ESG) criteria. This requires prioritizing effective waste management and recycling practices. Overall, it is impossible to overestimate the importance of ESG in environmentally friendly disposal. It is the impetus behind waste management techniques that are socially and environmentally responsible, paving the way for a more sustainable and greener future. In addition to adopting

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renewable energy technologies, let's embrace ESG principles to fulfill our social and environmental obligations and leave a sustainable energy legacy for future generations. In this section, we discuss how effective ESG principles can effectively enhance the reputation of organizations when they consider environmental impact, effective governance and social responsibility in the conduct of their operations.

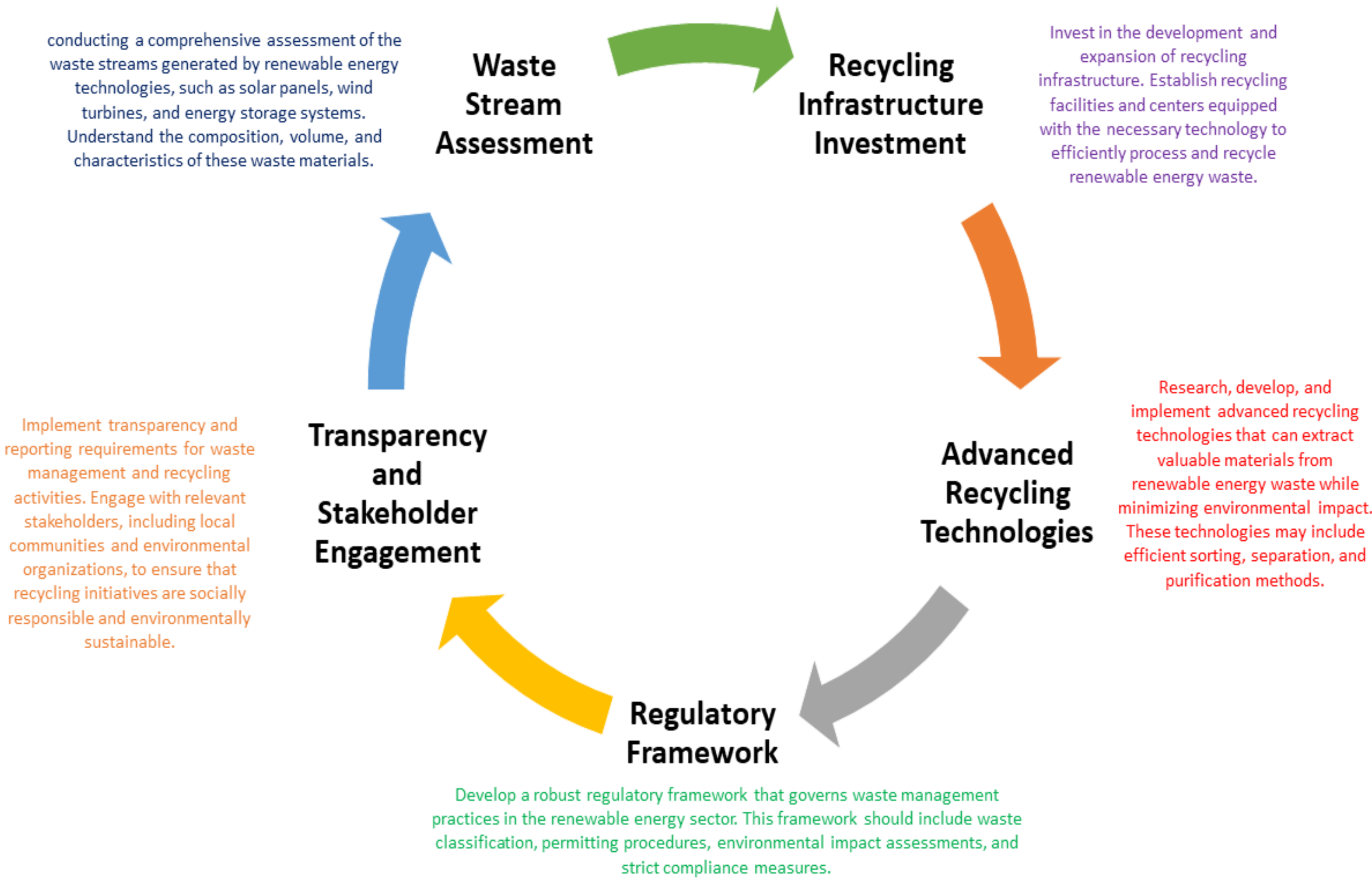

Figure 2. Steps to of circular decarbonized recycling of renewable energy waste.

3.1 Case studies, best practices and lessons learnt

Investigating case studies of effective end-of-life waste disposal strategies in the renewable energy industry provides important information about how ESG elements are integrated. This section highlights firms and locations that have demonstrated effective waste management in line with ESG principles, offering insights and repeatable methods. The first case study considered for the purpose of this review is First Solar's Recycling Program. First Solar is a leading manufacturer of thin-film solar panels. A thorough recycling operation for thin-film photovoltaic, or Photovoltaic (PV), panels has been put in place by First Solar. Cadmium telluride is a dangerous substance present in these panels. Fortunately, First Solar has recycled up to 90% of the materials used in these panels, efficiently managing their end-

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of-life disposal [62]. As a result, the environmental effect of garbage disposal is greatly reduced. Among their program's salient elements are Collection centers which functions to guarantee the secure gathering and conveyance of used panels to recycling facilities. First Solar set up collection centers using Advanced Recycling Technologies (ART) to recover valuable resources with the least amount of negative environmental impact. The enterprise uses sophisticated recycling methods in a transparent manner - keeping with the ESG values of accountability. First Solar reports on its recycling activities using a public approach. Another case study considered for this review is the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive. With the WEEE Directive, the European Union has adopted a comprehensive strategy for handling end-of-life waste from renewable energy systems. Strict guidelines are set forth in this directive for the gathering, recycling, and ecologically responsible disposal of electronic trash, which includes parts of solar panels and wind turbines. Important facets of this directive consist of; extended producer responsibility **-** producers bear the financial and administrative burden of arranging for the disposal, recycling, and treatment of waste equipment. This is consistent with the accountability principles of ESG. The also use minimum recycling targets to lessen the impact on the environment and conserve resources, the directive establishes precise criteria for the reuse and recovery of elements from electronic waste. Information and Awareness forms a critical component for the promotion of community involvement, the EU supports public education and awareness campaigns that educate consumers about the need of properly disposing of electronic waste.

These case studies provide numerous valuable insights and scalable methodologies with Lessons learned and replicable practices from various perspectives. By making an investment in cutting-edge recycling technology to reduce environmental impact and recover valuable materials, businesses, this can help manage end-of-life trash effectively. Furthermore, enforcing greater producer responsibility, as outlined in the EU's WEEE Directive, businesses can be held accountable for the full life cycle of their products, in line with the accountability principles of ESG. Although, transparency and reporting forms part of accountability; yet ESG standards must be upheld to when waste management initiatives are reported. This will encourage transparency of businesses and make available public information about waste management plans. Another important reference from the case studies is to be socially conscious when interacting with local communities and raising awareness of the value of efficient garbage disposal; this must be done with absolute support of laws and regulations, like the WEEE Directive, are frequently necessary for effective waste management. Legislators ought to think about passing laws that support ethical trash management.

It is worthy to note that; these case studies demonstrate the possibility of implementing ESG concepts into end-of-life waste disposal procedures that are successful in the renewable energy industry. Businesses and localities may imitate these best practices and help to create a more environmentally friendly and responsible energy future by investing in cutting-edge recycling technologies, enforcing greater producer accountability, and encouraging transparency and community participation.

4.0 Sustainable disposal of wastes from renewable energy resources

Organizations and governments can optimize waste disposal methods for renewable energy technology with the use of Environmental, Social, and Governance (ESG) frameworks. This section explores the diverse impact of ESG on waste management, with a focus on accountability, transparency, and stakeholder involvement. It also emphasizes the role that investors and shareholders play in promoting the adoption of ESG principles. Governmental agencies and other enterprise can use ESG frameworks as a set of guiding principles to ensure that their waste disposal methods are in line with ethical and sustainable standards. The integrated strategy that takes governance, social, and environmental aspects into account when disposing of waste from renewable energy sources in a sustainable manner is therefore

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covered in this section. With this strategy, the renewable energy industry is guaranteed to adopt ethical and sustainable waste management techniques that meet global sustainability goals.

Three main points are highlighted by these frameworks as depicted in figure 3:

A. Environmental Considerations: ESG guidelines emphasize how important it is to reduce waste disposal's negative environmental effects. This entails resource conservation, appropriate waste treatment, and recycling. Organizations are encouraged by ESG to implement life cycle assessments and take into account the full environmental impact of waste disposal from birth to death.

B. Social Responsibility: By addressing the labor and community components of garbage disposal, ESG encourages social responsibility. This entails guaranteeing these communities receive fair benefits and taking into account the welfare of the communities impacted by waste disposal methods. It also includes labor-related issues including worker safety and ethical labor practices.

C. Corporate Governance: In order to hold businesses responsible for the disposal of their waste procedures, corporate governance is essential to waste management. ESG frameworks promote accountability, openness, and moral decision-making in waste management procedures.

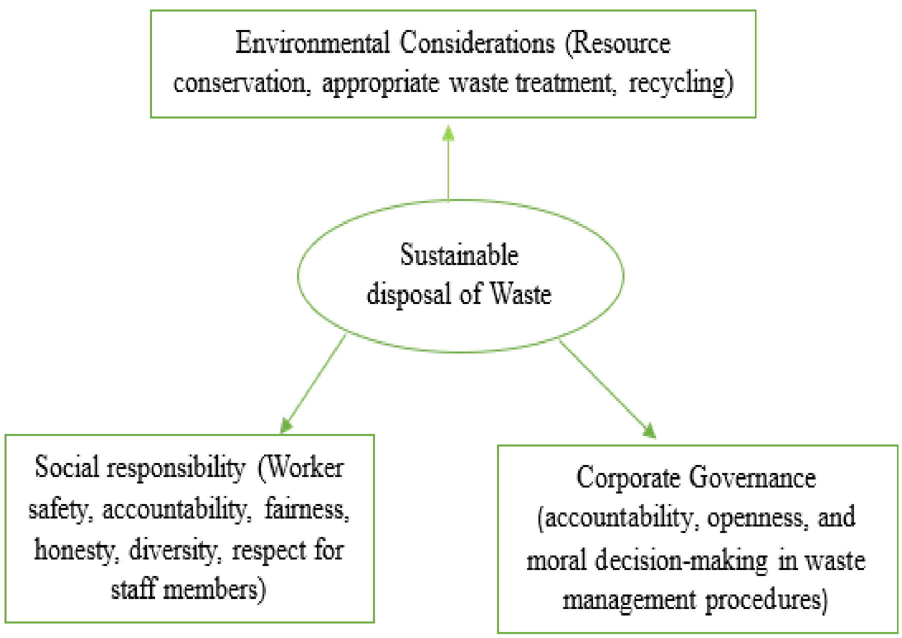

Figure 3. Framework for sustainable disposal of Renewable energy waste

4.1 Stakeholders Engagement

Stakeholders' participation, accountability, and transparency are essential elements of implementing ESG in garbage disposal. This will further foster transparency. Governments and enterprises are encouraged by ESG principles to be open and honest regarding their waste management initiatives. Reports on trash production, disposal techniques, and environmental effect analyses are all included in this transparency. Transparent reporting holds companies responsible

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for their actions and enables stakeholders to evaluate the social and environmental effects of trash disposal. Besides, one of the critical cornerstones of ESG is accountability. Governments and organizations are responsible for making sure waste management follows ESG guidelines. This responsibility could be in the form of observing regulations, paying fines or penalties, or facing legal repercussions for noncompliance. Stakeholder's engagement is recommended by ESG principles because it entails actively including relevant parties and impacted communities in waste disposal decision-making processes. Businesses are greatly influenced by shareholders and investors to implement ESG waste management principles. Some of the ways shareholders and investors influence businesses are to increasingly take into account environmental, social, and governance (ESG) aspects. Investors might decide to favor some businesses that exhibit ethical waste management techniques in line with ESG guidelines. Therefore, businesses that put an emphasis on ESG in waste management can draw in more investors. Although, through activism and resolution voting on ESG matters, shareholders can have an impact on firms. Some of the resolutions from stakeholders' forums may advocate for more sustainable practices, equal benefits for impacted communities, and increased transparency in waste management through effective financial performance. Long-term profitability may be enhanced by businesses that give ESG principles first priority when managing trash. Investors and stockholders may also find sustainable waste management strategies appealing because they can lower costs, lessen environmental responsibilities, and improve a company's reputation. Significantly, ESG frameworks function as heuristics that optimize waste management plans for renewable energy technology. They place a strong emphasis on governance, social, and environmental issues, with stakeholder involvement, accountability, and transparency being essential to the implementation of ESG. Moreover, the consequence of harmonizing waste disposal methods with sustainability and accountability is highlighted by the impact of investors and shareholders in promoting the use of ESG principles in waste management.

4.2 Challenges and Future Directions

No doubt, sustainable disposal of renewable energy components are faced with some challenges, and it is important for this review to specify some future directions. Although the transition to a system based on renewable energy offers hope for a better future for the earth, there are obstacles along the way, particularly with regard to sustainable disposal. Highlights of areas prepared for research, policy development, and innovation while discussing the challenges encountered in the sustainable disposal of renewable energy components. It also makes recommendations for future paths. Some of the constraints affecting sustainable disposal of renewable energy components include technological limitations**.** Despite advancements in recycling technologies, certain elements found in renewable energy elements cannot be recycled effectively. Retrieving and reusing certain rare materials, such as those used in wind turbines and solar panels, is still difficult.

Considering some economic factors, sustainable disposal techniques may not necessarily be the most profitable. Businesses may be discouraged from investing in environmentally friendly disposal due to the expenses of recycling and repurposing materials due to regulatory variability**.** In other words, distinct national and regional regulatory frameworks pertaining to garbage disposal result in disparities in standards and practices. The situation is made more difficult by the lack of a single worldwide standard and logistical challenges**.** Number of components that requires disposal are fast increasing along with the use of renewable energy sources therefore, managing higher throughput without sacrificing environmental sustainability possess a very huge challenge.

Overall major complication is the lack of knowledge among stakeholders and consumers about the significance of sustainable disposal and the means by which it can be accomplished effectively.

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5.0 Summary and Conclusion

This article has carried out a very comprehensive review of environmental, social, and governance (ESG) aspects of disposing of end-of-life waste for renewable energy systems. It further examined the importance of this subject as a global fight against climate change from the renewable energy sources perspective. Although the renewable energy technologies promise a more sustainable and clean future, disposing their components after use poses a number of issues that need to be resolved urgently. There are dangers posed to the environment and public health when disposing of components used in renewable energy, as they frequently contain toxic elements. For instance, electronic components are frequently found in renewable energy systems, like wind turbines and solar panels. To keep dangerous elements out of the environment, these electronics must be disposed of and recycled properly. Numerous renewable energy systems depend on specific elements might also require a lot of resources to extract, including rare earth metals. Reducing the negative environmental effects of production and disposal of these materials therefore requires the establishment of efficient recycling and recovery procedures which has been reviewed in this article. Certain parts of renewable energy technologies, such solar panels, could include dangerous substances like cadmium and lead. Utilizing safe recycling and disposal techniques is therefore necessary to avoid tainting the environment.

The magnitude of decommissioning initiatives is anticipated to rise in tandem with the ongoing expansion of renewable energy infrastructure. This calls for careful planning and the application of disposal techniques. The recycling and disposal of renewable energy technology require well-defined legislative frameworks. Managing end-of-life waste requires effective governance and regulatory activities. It can be concluded that ESG guidelines can help governments and organizations optimize their waste disposal plans while maintaining stakeholder participation, accountability, and openness. These rules ought to encourage sustainable behaviors while addressing safety and environmental issues. The development of more effective and long-lasting recycling methods for renewable energy technology requires research and development work. It is also essential for industrial players, legislators, researchers, and environmentalists to collaborate in addressing disposal issues and provide feasible solutions. Overall, comprehensive lifecycle evaluations can be directed towards the creation of more sustainable methods and technologies by identifying possible adverse effects on the environment at every phase, including disposal.

5.1 Recommendations and Future work

The following recommendations are therefore drawn from this review. Firstly, that investing in research and development for disposal technologies should be taken more seriously by public and private organizations with top priority. This will develop environmentally friendly methods of disposing of and recycling components of renewable energy. It will further encourage finding more effective ways to extract uncommon minerals or biodegradable component solutions. Understanding the full life cycle of technologies that produce renewable energy should be the main goal of future research with reference to innovations that reduce waste at every stage of an item's lifespan, from production to decommissioning, can come from a holistic perspective. On the other hand, international organizations ought to endeavor to provide unified guidelines for the environmentally friendly disposal of components used in renewable energy sources. This can promote uniformity and establish a standard for other nations.

Making lucrative incentives available for Sustainable Disposal**,** effective collaborations among stakeholders at local, regional, and global level is very important. This will also foster public awareness campaigns among others. It is evident that the need for environmentally friendly disposal solutions grows as the world's energy use becomes increasingly widespread. Through recognition of obstacles and proactive pursuit of future paths, interested parties may guarantee that the revolution in renewable energy is genuinely sustainable in every meaning of the term.

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