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Data-Driven Strategies for Optimizing Albania's Utilization of Renewable Energy Sources from Urban Waste: Current Status and Future Prospects

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Abstract: Albania is now implementing a range of steps as part of its journey towards European Union integration, based on agreements that have been achieved. Key to these initiatives is the extensive adoption of circular economy concepts through comprehensive waste management systems. This collaboration is based on systematically implementing measures that align with the fundamental principles of the waste management hierarchy. Albania wants to lead in waste-to-energy conversion exploration by focusing on trash minimization, reuse, recycling, and energy generation from residual waste. Although there has been notable advancement, especially in aligning laws with EU requirements, there are practical obstacles, especially in the execution of waste-to-energy projects. The challenges involve the need for effective waste segregation, higher recycling rates, and the use of advanced waste-to-energy technologies. The essay utilizes meticulously selected data on Albania's waste generation from reputable organizations and the legal framework regulating waste management to assess the current situation and predict future possibilities, which may be advantageous for government ministries and agency platforms.

Keywords: urban waste; circular economy; waste-to-energy; waste hierarchy

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1. Introduction

The global imperative for sustainable development has catalyzed a paradigm shift in economic models, prompting the widespread adoption of circular economy principles [1–3]. This transformative approach advocates for the optimization of resources through closed-loop systems, wherein products and materials are reused, recycled, and repurposed to minimize waste and environmental impact. The management of waste is an essential component in addressing the impact on the environment and it is something that a variety of industries can be involved in [4–7]. Albania, amidst its journey toward European Union integration, has emerged as a proactive participant in this transition, spearheading initiatives aimed at embracing the circular economy ethos [8].

On the other hand, sustainable development is defined as living, producing, and consuming in a way that meets current needs without compromising the ability of future generations to meet their own needs [9,10]. It is one of the goals of the 21st century and should be implemented at local, national, and international levels. From this perspective, its implementation is essential in every field, particularly in energy production and waste management [11–13].

The sustainable production of energy and the sustainable development of integrated waste management are closely interconnected. On the one hand, a sustainable energy supply to meet the ever-growing demands of development necessitates the utilization of alternative and clean energy resources. Moreover, sustainable waste management ensures the use of renewable energy resources through the efficient utilization of natural resources [14–16]. Through the latter, there is also a promotion of waste reduction, reuse of recyclable materials, and harnessing the energy value of waste, resulting in the least possible impact on the environment [17,18].

The process of harnessing the energy value of waste, particularly non-recyclable waste, is known as the waste-to-energy process. This involves converting waste into useful energy (heat and electricity) and combustible materials (methane, biodiesel, oils, and bio-alcohols). Besides increasing the economic value of waste, this process reduces the remaining amount destined for landfills, thereby positively impacting environmental parameters. Specifically, it reduces greenhouse gas emissions, diminishes the need for energy generation from fossil fuels, decreases the demand for landfills, and contributes to sustainable management of solid urban waste. Additionally, it has a positive impact on economic growth. Due to all these mentioned benefits, the United States Environmental Protection Agency has classified municipal solid waste (MSW) as a renewable energy source [19].

In tandem with sustainable development and circular economy aspirations, Albania as a Balkan state confronts a myriad of challenges and opportunities in its waste management landscape [20–22]. The country's urban centers grapple with mounting waste generation, exacerbated by rapid urbanization and industrialization. In response, Albania has embarked on an integrated trajectory, seeking to mitigate environmental degradation while fostering economic resilience [23]. This strategic endeavor encompasses the harmonization of waste management practices with EU standards and directives, positioning Albania on a trajectory toward sustainable development and global competitiveness [18,24]. Within this context, the exploration of renewable energy sources assumes paramount significance. Albania, endowed with abundant natural resources and untapped potential, stands poised to leverage renewable energy as a cornerstone of its sustainable development agenda. Central to this endeavor is the harnessing of energy from urban waste, offering a twofold solution to environmental and energy challenges [25–27]. Waste-to-energy technologies present viable pathways toward reducing dependence on fossil fuels, mitigating greenhouse gas emissions, and fostering energy security.

As Albania navigates the complexities of its transition, waste management emerges as a requirement in its sustainable development narrative [27,28]. The convergence of circular economy principles [29], Albania's evolving socio-economic landscape, and the imperative for renewable energy integration underscores the intricate interplay between environmental stewardship, economic prosperity, and social equity. Against this backdrop, this paper endeavors to elucidate Albania's present state and future challenges in harnessing renewable energy from urban waste, offering insights into policy imperatives, technological innovations, and strategic pathways toward a more sustainable future.

The 2030 Agenda for Sustainable Development was introduced in September 2015 during the United Nations Summit, with the involvement of 193 member countries, including Albania. The agenda intends to implement effective policies over a 15-year period to eliminate poverty in all its manifestations. The Summit and the adoption of the 2030 Agenda for Sustainable Development demonstrated a strong worldwide dedication to tackling urgent environmental issues such as waste management and the use of renewable energy. Albania is focusing on waste reduction, recycling, and promoting renewable energy sources to achieve Sustainable Development Goals 11 and 7. Seventeen major objectives

were set under this framework to help participating countries achieve sustainable, inclusive, and ecologically friendly development. Some of these goals include "Clean and affordable energy", "Clean water", "Sustainable cities and communities", "Responsible consumption and production", and more [30].

The European Union (EU) directive 2000/76/EC [31] on Waste Incineration has implemented measures to mitigate the environmental and health risks associated with waste incineration. This directive aims to prevent or reduce pollution of air, water, and soil resulting from the incineration or co-incineration of waste, as well as to minimize associated risks to human health. Key provisions of the directive include scope and application, wherein it applies to both solid and liquid waste incineration plants, as well as co-incineration plants, excluding experimental facilities treating less than 50 tons of waste and specific types of waste like certain agricultural and forestry waste, radioactive waste, and animal carcasses. Operators of incineration and co-incineration plants must obtain permits from competent authorities, ensuring compliance with the directive's requirements. Permits specify waste categories, plant capacities, and procedures for monitoring pollutants. Operators must also take precautions during waste delivery and reception to prevent negative environmental effects and risks to human health. Additionally, prior to accepting hazardous waste, detailed information on waste characteristics and generating processes must be possessed. The directive mandates maintaining incineration or co-incineration gases at temperatures of at least 850 °C for two seconds to ensure complete waste combustion, with higher temperatures required for hazardous waste containing halogenated organic substances.

By adhering to such directives, EU member states aim to promote sustainable waste management practices while safeguarding environmental and public health. Emission limit values for incineration plants, covering heavy metals, dioxins, furans, carbon monoxide, dust, organic carbon, and other pollutants, are set out with specific provisions outlined for co-incineration plants. Moreover, incineration and co-incineration plants must obtain permits for discharging water used in exhaust gas cleanup, ensuring compliance with emission limit values set out. Residues from incineration or co-incineration processes must be minimized and, where possible, recycled, with tests required to assess residue characteristics and pollution potential. Measurement systems must be installed to monitor installation parameters and emissions to air and water continuously or periodically. Through these measures, the EU aims to prevent or reduce air, water, and soil pollution caused by waste incineration, while promoting the sustainable management of waste resources.

Actually, waste-to-energy conversion is part of a broader scheme of principles on which waste management systems are based. The selection of the most suitable method depends on the climatic conditions, population, type of waste generated, and geographical conditions of the region. According to the guiding principles outlined in the waste management law in [18], the most advisable option is to prevent waste generation and less advisable is the landfilling of waste without energy recovery. Between these two options, there are various treatment options for waste. Energy can be derived from treating MSW through both energy and non-energy routes. Recycling, reusing, and composting fall into the non-energy routes. Recycling involves using materials like plastics, metals, and paper/cardboard to create new products. This would result in reducing the amount of waste sent to landfills and minimizing pollution. Composting is the biodegradation of organic waste. This process involves separating compostable and inert materials and producing compost and inert briquettes.

This study aims to assess Albania's utilization of renewable energy sources from urban waste, focusing on data-driven strategies. Specifically, it seeks to evaluate waste management practices, identify challenges and opportunities in waste-to-energy conversion, and provide recommendations for optimization.

The hypotheses proposed are:

- Albania has made progress in aligning waste management practices with EU directives;
- Challenges exist in implementing waste-to-energy technologies, including waste segregation and recycling rates;
- Data-driven strategies are critical in optimizing renewable energy utilization from urban waste.

In addition to the objectives outlined above, this study will also undertake a bibliometric analysis to further explore trends and patterns in waste management and renewable energy utilization. By analyzing scholarly publications in this field, bibliometric analysis will provide valuable insights into the current research landscape and identify key areas for future investigation.

Bibliometrics and Statistical Analysis

The bibliometrics analysis undertakes a rigorous examination of scholarly articles retrieved from the Scopus database, utilizing this technique to gather insights into waste, energy, and renewable-related research. A comprehensive search yielded approximately 1000 articles, which were subjected to accurate evaluation utilizing R programming to extract valuable information.

Firstly, the results of the analysis showed key trends and patterns within the corpus of articles. Figure 1 presents a Sankey diagram depicting the complex interplay between countries, keywords, and sources across the scholarly landscape. Notably, Italy and China emerge as the most prolific contributors to the discourse, underscoring their active engagement in waste, energy, and renewable-related research. Furthermore, the primary keywords driving research exploration include "circular economy" and "renewable energy", indicative of the overarching thematic focus within the scholarly discourse. Journals such as Energies and Sustainability emerge as prominent sources, reflecting their significance as dissemination platforms for cutting-edge research in the field.

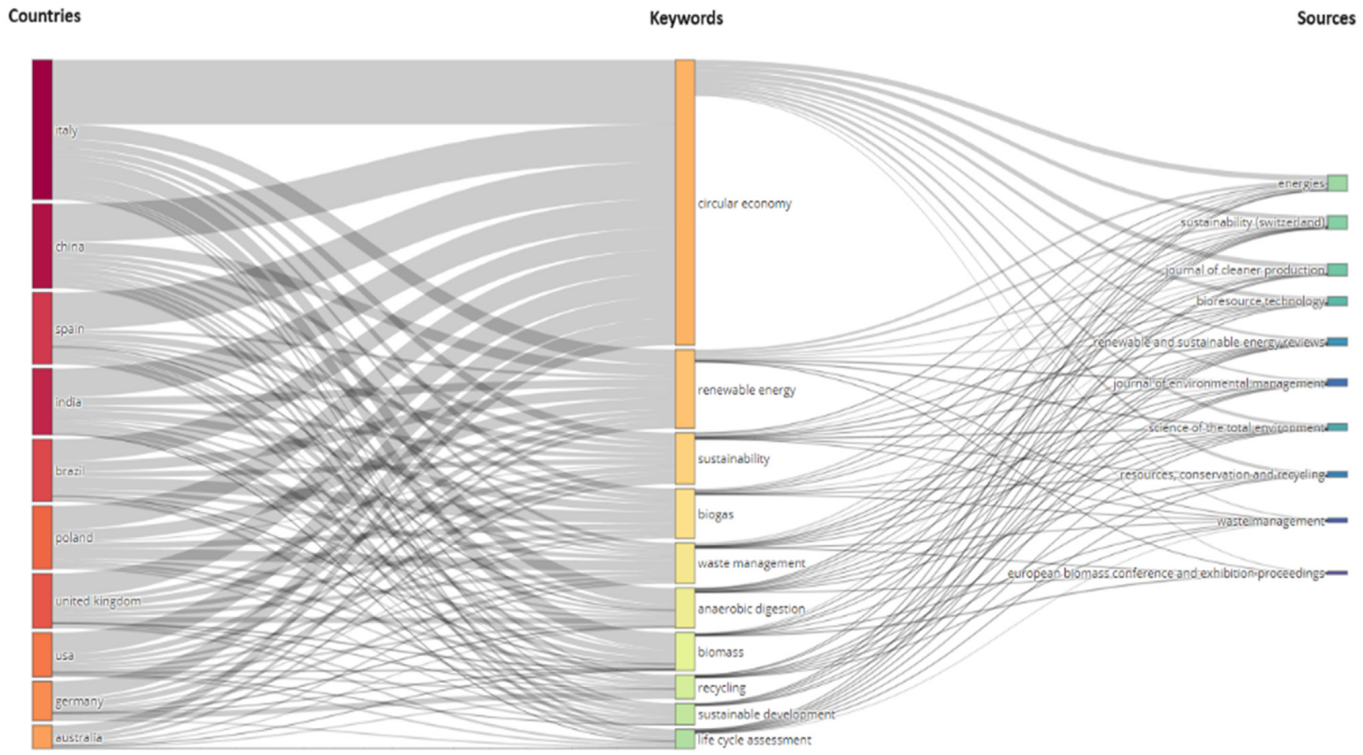

Figure 1. Sankey diagram illustrating country, keyword, and source distribution in waste, energy, and renewable-related scholarly articles.

In addition to the Sankey diagram, Figure 2 unveils a co-occurrence network, unveiling the complex relationships between concepts within the scholarly discourse. This network analysis offers valuable insights into the interconnectedness of key thematic areas and the prevalence of overarching concepts driving research inquiry. By visualizing the co-occurrence patterns between terms, this analysis shows clusters of related concepts, facilitating a deeper understanding of the thematic landscape and the interdisciplinary nature of waste, energy, and renewable-related research.

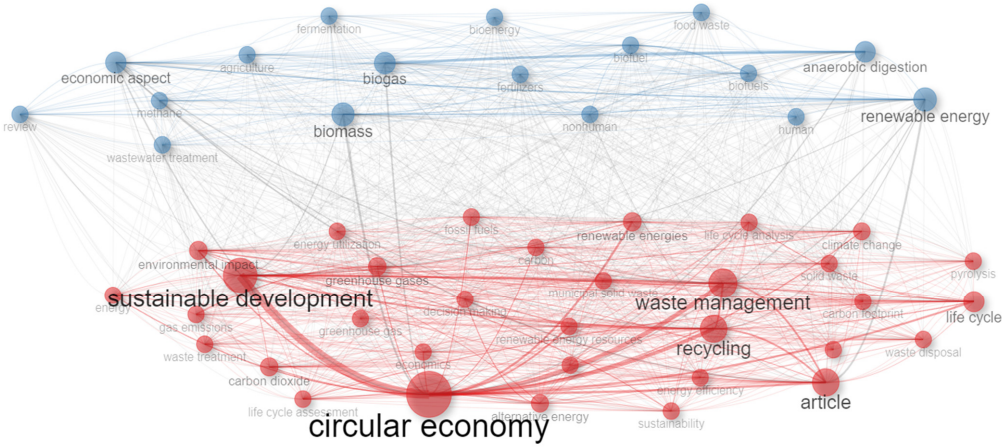

Figure 2. Co-occurrence network analysis of concepts in waste, energy, and renewable-related scholarly articles.

In addition to the bibliometric analysis, the statistical examination based on data sourced from Statista concerning the installed capacity of municipal waste energy in Europe spanning from 2010 to 2022 is shown in Figure 3. This underscores a notable trend of capacity expansion, reflecting a growing recognition of waste-to-energy initiatives as a viable means of addressing energy needs while concurrently mitigating environmental impacts associated with waste disposal. By charting the trajectory of capacity growth, Figure 3 provides valuable insights into the evolving landscape of waste management practices and their pivotal role in shaping sustainable energy solutions across Europe.

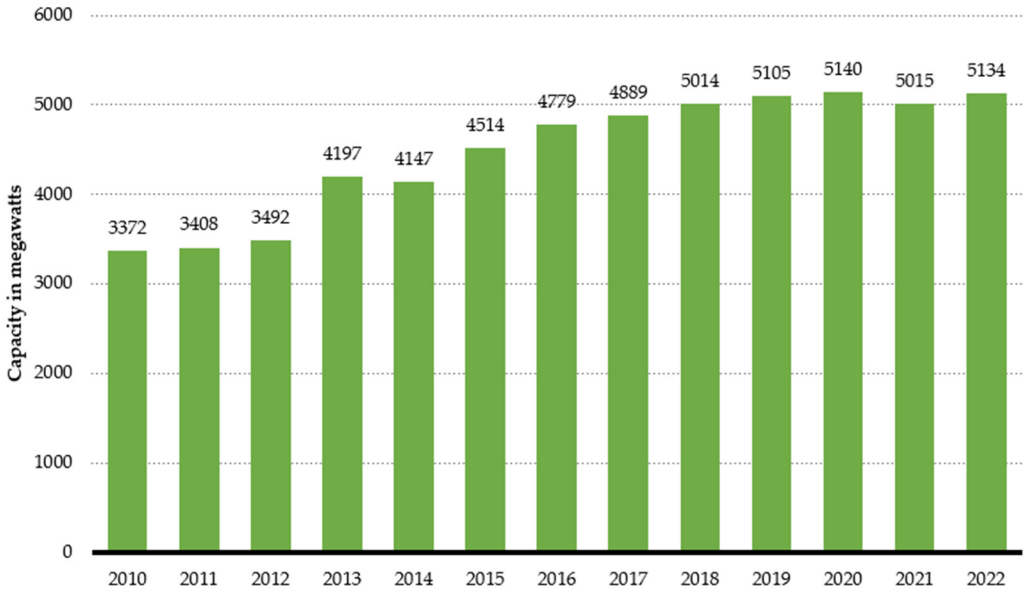

Figure 3. Installed capacity of municipal waste energy in Europe (2010–2022): trends and growth potential in megawatts [32].

2. Materials and Methods

This article provides an analysis of the waste management approach concerning solid waste in Albania, specifically focusing on the recovery of energy value contained in waste. Information regarding Albanian waste legislation and waste statistics published by INSTAT (Institute of Statistics of Albania) has been utilized for this purpose. The main methodologies used are the following:

2.1. Legislative Approach to Waste Management

Review of Legislation: A comprehensive review of Albania's legislative framework governing waste management was conducted, with a focus on statutes, regulations, and directives issued by relevant governmental bodies, including the Ministry of Environment and the Institute of Statistics of Albania (INSTAT) [33]. This review encompassed laws related to waste prevention, collection, transportation, treatment, and disposal, as well as regulatory instruments addressing environmental protection, public health, and sustainable development.

Legal Analysis: The legal provisions pertaining to waste management were analyzed to identify key principles, rights, obligations, and enforcement mechanisms outlined in the legislative framework. Emphasis was placed on understanding the alignment of Albania's waste management laws with international standards, European Union directives, and circular economy principles.

2.2. Main Principle of Integrated Waste Management System

Conceptual Framework: The main principle of the Integrated Waste Management System (IWMS) was elucidated through a conceptual framework derived from scholarly literature, government reports, and policy documents. This framework delineated the core components of IWMS, including waste minimization, source separation, collection, recycling, composting, energy recovery, and landfilling.

2.3. Waste Generation and Management in Albania

Data Collection: Data on waste generation and management practices in Albania were sourced from official statistical publications and reports published by INSTAT. These datasets encompassed quantitative information on MSW generation rates, composition, collection coverage, treatment facilities, and disposal methods.

2.4. Albania's Approach to Waste-to-Energy Conversion Methods

Technology Assessment: A comprehensive assessment of waste-to-energy (WtE) conversion methods was undertaken to evaluate Albania's approach to energy recovery from waste. This assessment encompassed thermal technologies (e.g., incineration, pyrolysis, and gasification) and biological processes (e.g., anaerobic digestion, fermentation).

Techno-Economic Evaluation: Techno-economic analyses were performed to assess the technical feasibility, environmental sustainability, and economic viability of different WtE technologies in the Albanian context. Parameters such as energy efficiency, emissions mitigation potential, capital costs, operational expenses, and revenue streams were considered in the evaluation process.

Policy Analysis: An analysis of Albania's policy framework related to WtE technologies was conducted to understand regulatory incentives, barriers, and priorities shaping the adoption and deployment of energy recovery facilities. Policy instruments supporting WtE investments, such as feed-in tariffs, subsidies, and tax incentives, were reviewed to assess their effectiveness in promoting renewable energy generation from urban waste.

The chosen methodologies contribute significantly to the research objectives by providing a comprehensive analysis of waste management practices and energy recovery strategies in Albania. By considering legislation, analyzing data on waste generation and management, and assessing waste-to-energy conversion methods, the study offers an understanding into regulatory frameworks, current practices, and opportunities for renewable energy utilization. These methodologies collectively provide a robust foundation for

examining Albania's approach to waste management and its transition toward sustainable energy solutions.

3. Results and Discussion

3.1. Albania's Legislative Approach to the Waste Management

Within the framework of the Stabilization and Association Agreement (SAA) signed in June 2006 and entering into force on 1 April 2009, between Albania and the European Union (EU), Article 108, entitled "Environment", obliges Albania to develop and strengthen cooperation in the pursuit of a sustainable environment. The process began with the harmonization of Albanian legislation with that of the EU, being carried out in accordance with the National Plan for European Integration (NPEI), specifically its Chapter 27, "Environment and Climate Change". This chapter is among the most crucial, as it encompasses 73 directives and regulations, constituting the legal framework of the EU in the field of the environment and climate change.

As a result, three main laws have been drafted: Law No. 10431, dated 9 June 2011, "On Environmental Protection", amended; Law No. 10463, dated 22 September 2011, "On Integrated Waste Management", amended; and Law No. 8094/1996, "On the Public Disposal of Waste", which provides a legal basis, enabling municipalities to contract services to third parties, along with a series of Council of Ministers' Decisions regulating stakeholders' access to waste and their classification (VKM No. 99, 18 February 2005, "On the Approval of the Albanian Catalog of Waste Classification", amended) as well as their management according to specific criteria, utilization of energy value through waste incineration (VKM No. 178, 6 May 2012, "On Waste Incineration"), and final disposal through landfilling (VKM No. 452, 11 July 2012, "On Waste Landfills").

The objectives and main provisions of Law No. 10431 and Law No. 10463 regarding waste management in Albania and its compliance with EU standards are outlined. Law No. 10431 emphasizes environmental protection by setting goals to prevent, control, and decrease pollution, preserve nature and biodiversity, involve the public in environmental issues, encourage responsible use of natural resources, protect cultural and aesthetic values, and ensure human health and well-being. Law No. 10463 pertains to integrated waste management in Albania and sets out general regulations for its handling. This involves implementing strategies to prevent or reduce adverse effects caused by waste generation and handling, with a focus on conserving resources and enhancing the efficiency of waste utilization.

On this legal basis, a series of planning documents have been drafted, where the most important one is the "Strategic Waste Management Policies Document 2020–2035", serving as the foundational document for planning municipal, non-municipal, and hazardous waste management in Albania. Simultaneously, the "National Sectoral Plan" for the management of solid waste has been developed as a secondary-level planning document for waste management, mainly outlining the planning framework concerning investments in national-level infrastructure. To support the implementation of these aforementioned documents, the ministry develops "Regional/Zonal Plans" for each waste management area based on feasibility studies. Finally, each local governance unit formulates the "Local Integrated Waste Management Plan" for the territory under its jurisdiction, in accordance with the national and regional integrated waste management plans.

The institutional framework for waste management in Albania is organized through several institutions and agencies that have specific responsibilities in this field. Within this framework, some of the key institutions are the ministries responsible for the environment and infrastructure, which are the main institutions responsible for the development and implementation of policies and strategies in the environmental field, including waste management; other ministries responsible for finances, agriculture, and health, which contribute to waste management through various means and by addressing different aspects of the waste management process; the National Agency for Environment (AKM), which monitors, evaluates, and reports on the state of the environment in Albania; the Committee for Integrated Waste Management (CIWM), which is a newly established institution; the National Agency for

Water Supply and Sewerage and Waste Infrastructure (NAWSSI); the National Agency for Territory Protection (AKMT); municipalities and local authorities, as responsible for waste management at the local level, organizing collection, transportation, and treatment systems for various types of waste within their territories in accordance with local and national laws and regulations; producers and other businesses legally obliged to ensure proper management of products throughout their life cycle, from production or import to disposal; and, lastly, the citizens, who should play a significant role in the process of separate collection of waste (National Sectoral Plan for Solid Waste Management).

Although there has been significant progress in this direction, there are still challenges that need to be addressed, with the primary concern being the applicability of legislation as it requires financial support. In addition, Albania faces several challenges in its legislative approach to waste management, deterring effective implementation and enforcement of regulations. These challenges include inconsistencies and gaps in legislation, which lead to confusion among contributors, limited regulatory capacity resulting in lax enforcement, weak institutional coordination leading to inefficiencies, insufficient resources and infrastructure impeding investments, and a lack of public awareness and participation undermining efforts toward sustainable practices.

3.2. The Integrated Waste Management System in Albania (Main Principles)

After Directive 2008/98/EC [30], "Waste" represents any substance or object that the holder discards, intends to discard, or is required to discard. According to Albanian law and in compliance with the Directives of the European Union, waste management in Albania must be based on several principles. The main principle is the waste hierarchy, which is aimed at prioritizing waste management options according to what is best for the environment and human health, as well as the transition toward a circular economy.

In this sense, the preferred option is waste prevention, achieved by improving the efficiency of technological processes that produce waste or by extending the product's lifespan. The second option is the reuse of products for their primary purpose or for secondary purposes. Following this is recycling, which involves reprocessing waste materials to transform them into new products, followed by the recovery of the waste's energy value. The least preferred option is disposal through landfilling or in the sea, incineration, etc.

Although waste-to-energy conversion (recovery) is acknowledged for generating renewable energy and bringing about environmental and economic advantages, it holds the fourth position in the waste management hierarchy (Figure 4).

Its principal aim is to diminish waste volume before resorting it to landfill disposal. Thus, Albania should exercise caution when integrating it into the renewable energy production scheme. This alternative ought to be employed solely after the stages of prevention, reuse, and recycling have been exhaustively addressed. Consequently, the evaluation of feasibility and the establishment of waste-to-energy facilities should be restricted to handling the segment of waste that lacks alternative treatment options.

Other principles in waste management include concepts such as "The polluter pays", "Extended producer responsibilities", "The principle of prevention", and "The principle of mutual responsibility and cooperation", among others. These principles prioritize the separate collection of products and materials that present elevated environmental risks or demonstrate potential for recycling or recovery in the market.

Albania's waste management principles align with EU directives, particularly the waste hierarchy outlined in Directive 2008/98/EC. This hierarchy prioritizes waste prevention, followed by preparation for reuse, recycling, other recovery (including energy recovery), and, finally, disposal. In Albania, these principles inform waste management practices by emphasizing the importance of reducing waste generation, promoting recycling and reuse initiatives, and implementing energy recovery technologies. However, as this article describes, some improvements are needed for this alignment to become even closer. Nonetheless, these principles contribute to the transition toward a circular economy

by fostering a more efficient use of resources, reducing dependency on landfilling, and encouraging innovation in waste management technologies.

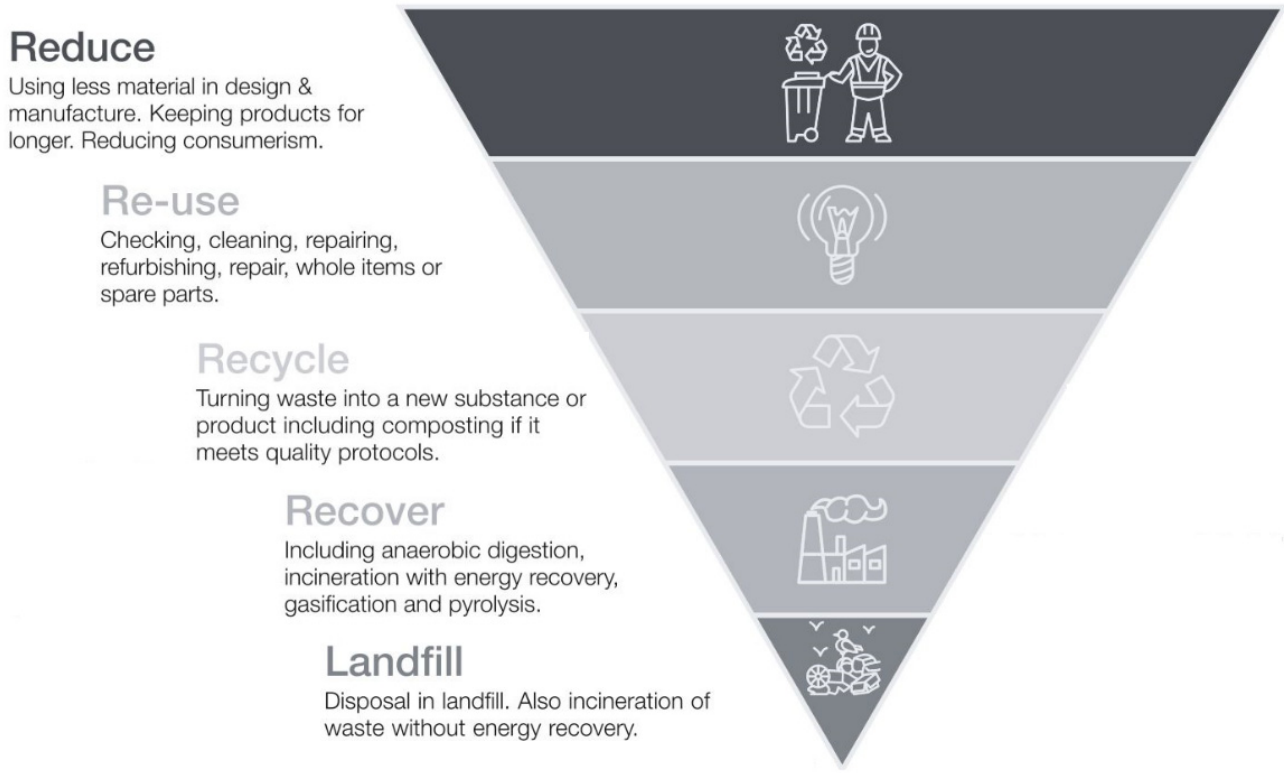

Figure 4. Waste hierarchy according to the EU Waste Framework Directive [34].

3.3. The State of Waste Generation and Current Management in Albania

3.3.1. The Monitoring and Reporting System

In principle, proper waste management requires the coordination of various activities, ranging from monitoring waste production (identifying producers, quantities, and waste characteristics) to considering the most suitable management approach (based on the aforementioned data). Therefore, the managerial decision-making hierarchy begins with the accurate and comprehensive reporting of waste production and characteristics.

In the Republic of Albania, waste monitoring should be based on the following criteria (VKM: 1189, 18 November 2009): annual quantities of production; waste distribution by municipalities and regions; pollutant component percentages; and merchandise composition of waste. These data should be generated by municipalities and reported to the responsible ministries, which further compile the annual waste statistics report submitted to the National Agency of Environment. Another institution involved in generating waste data is INSTAT, which, since 2019, has been utilizing the online questionnaire method across all municipalities in the country.

There are numerous ongoing challenges within the Albanian waste management system. These encompass inaccurate and insufficient environmental indicators, the absence of specialized collection methods that limit detailed information gathering, inadequate infrastructure for waste measurement and weighing, the lack of a systematic approach to measure and analyze waste composition, as well as the absence of a comprehensive monitoring and assessment system, particularly concerning waste. The primary concern remains the lack of data accuracy reliability due to the absence of a control system, underscoring the critical need to develop specific monitoring guidelines inclusive of indicators and criteria for data generation.

3.3.2. The System of Waste Collection/Depositing

The waste collection/depositing system in Albania also faces significant issues due to its characterized weak infrastructure. Waste is not always discharged into the designated landfills by municipalities. In many cases, especially in rural areas, waste is disposed of in nature. Additionally, not all landfills are supervised. At the national level, waste disposal takes place in 199 landfills, with only 5% of them being monitored (Table 1).

Table 1. Landfills monitored in Albania [24].

Nr.	Landfill	Capacity	Notes
1.	Bushat (Shkodër)	1,000,000 m^3	In action
2.	Bajkaj (Delvinë)	600,000 t	In action
3.	Sharrë (Tiranë)	2,900,000 t	In action
4.	Rubik	3500 t/year	Industrial landfill, In action
5.	Rrëshen	NA	In action
6.	Dibër	NA	In action
7.	Papër (Elbasan)	9970 t	In action
8.	Maliq	1,000,000 t	In action
9.	Fier		In action

The remaining part (95%) is unmonitored [24]. Lastly, despite efforts, there is not a proper sorting of waste by categories. Recyclable waste ends up mixed in landfills, not respecting the waste management hierarchy. From an energy utilization perspective, this is something positive since plastic, paper, and wood waste increase the energy capacity of the waste. However, this is not positive from an environmental standpoint.

Another issue related to this is the inability to make a comprehensive quantitative and qualitative assessment of the waste produced in Albania. This leads to inaccurate feasibility assessments and designs of waste-to-energy conversion plants.

3.4. Quantitative and Qualitative Assessment of the Waste Produced in the Territory of Albania

Figures 5–10 illustrate data on the quantity, quality, and management level of solid waste generated in Albania from 2020 to 2023. The graphical representation indicates a consistent decline in the amount of waste produced annually. Simultaneously, there is a notable upward trend in the management rate relative to the overall waste generation.

In Figure 5, non-urban waste Kg/Capita refers to the amount of waste generated per capita in areas outside of urban or metropolitan areas. This metric quantifies the volume or weight of waste produced by each individual residing in non-urban regions, typically measured in kilograms per capita (Kg/Capita). Non-urban areas often have distinct waste generation patterns compared to urban centers, influenced by factors such as population density, economic activities, and lifestyle choices. Waste composition in non-urban areas may vary, with differences in the types of materials discarded and the methods of waste disposal.

Over 80% of this waste constitutes household waste, while the remaining 20% comprises non-household waste (Figure 7). Furthermore, there is a noticeable decline in the amount of urban waste directed to landfills. This shift might be attributed to the operational effectiveness of the upper tiers within the waste management hierarchy. In Figure 7, the main industrial wastes generated in Albania include mining tailings, chemical by-products, metallurgical residues, construction debris, and hazardous waste. These wastes originate from various industrial processes such as manufacturing, construction, mining, and energy production. Understanding these waste streams is crucial for developing effective waste management strategies to minimize environmental impacts and promote resource recovery.

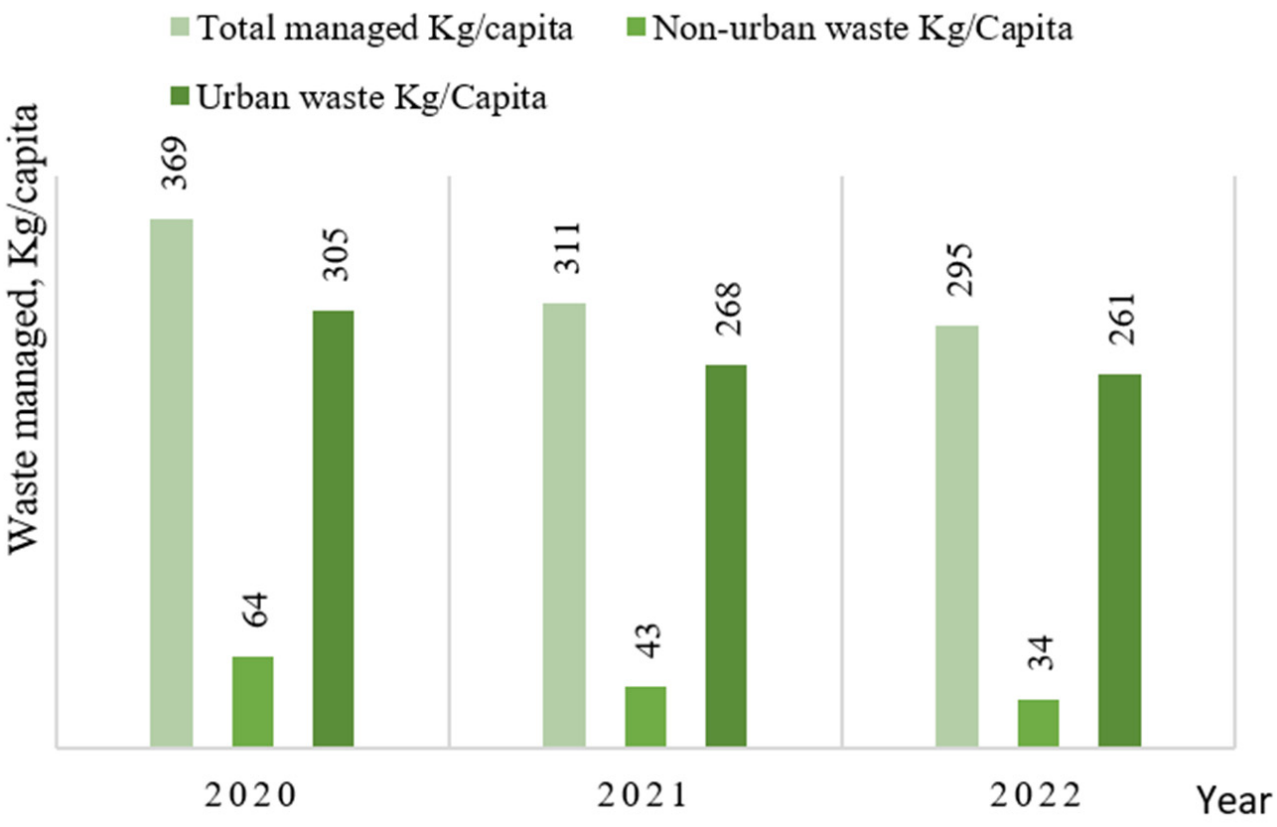

Figure 5. The amount of waste generated and managed in the territory of Albania [33].

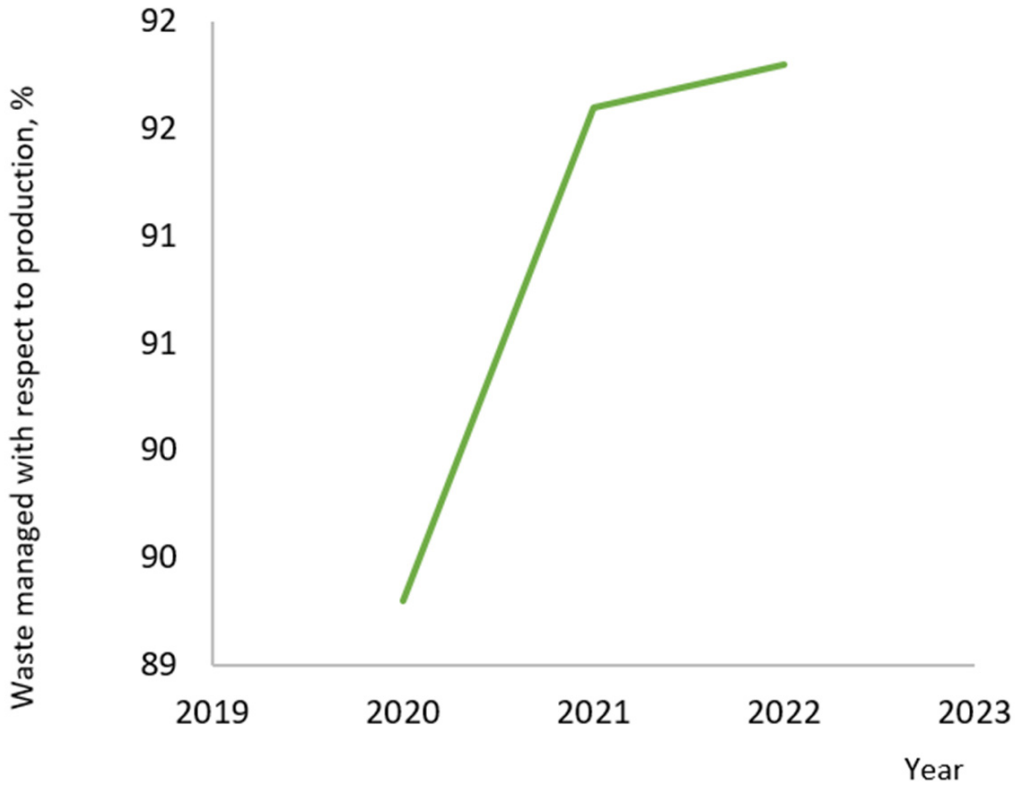

Figure 6. Management of waste in Albania in relation to the total amount of waste [33].

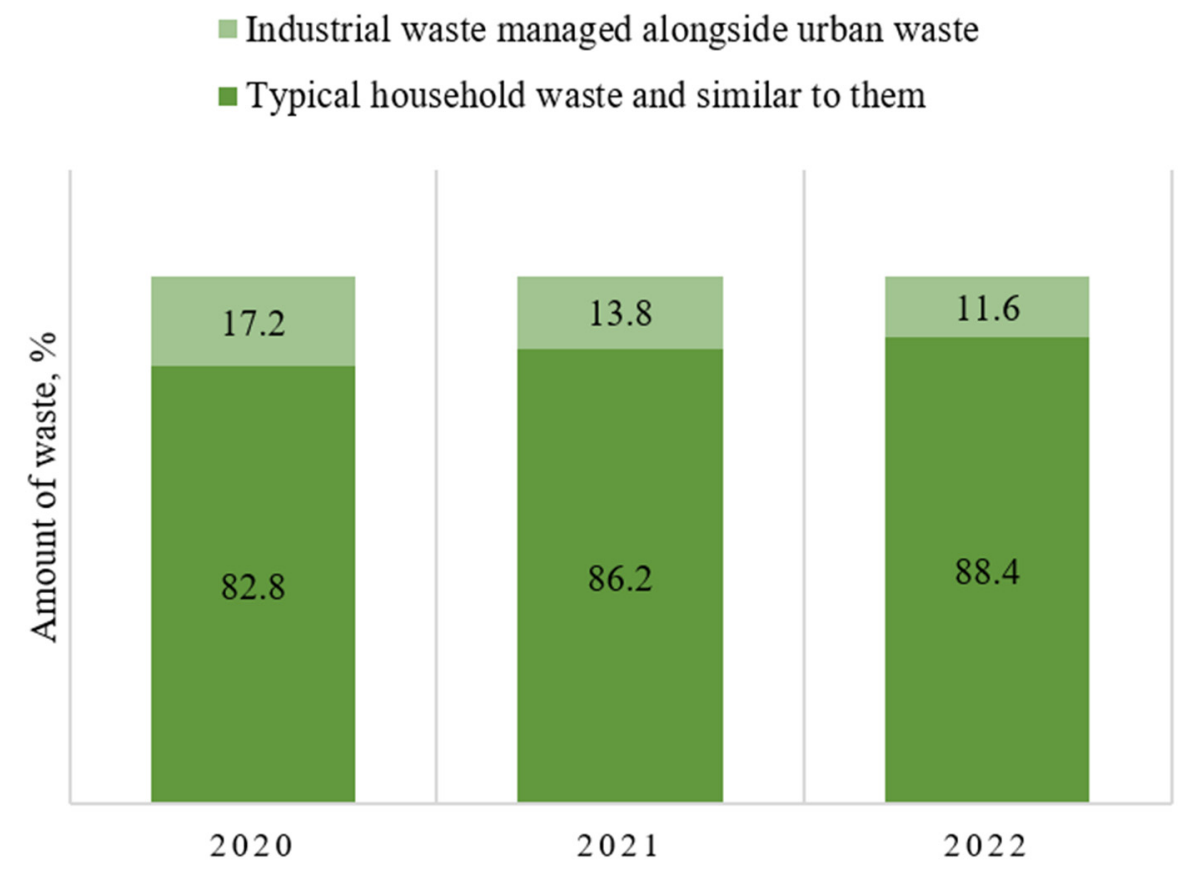

Figure 7. Waste is managed based on its origin in the territory of Albania [33].

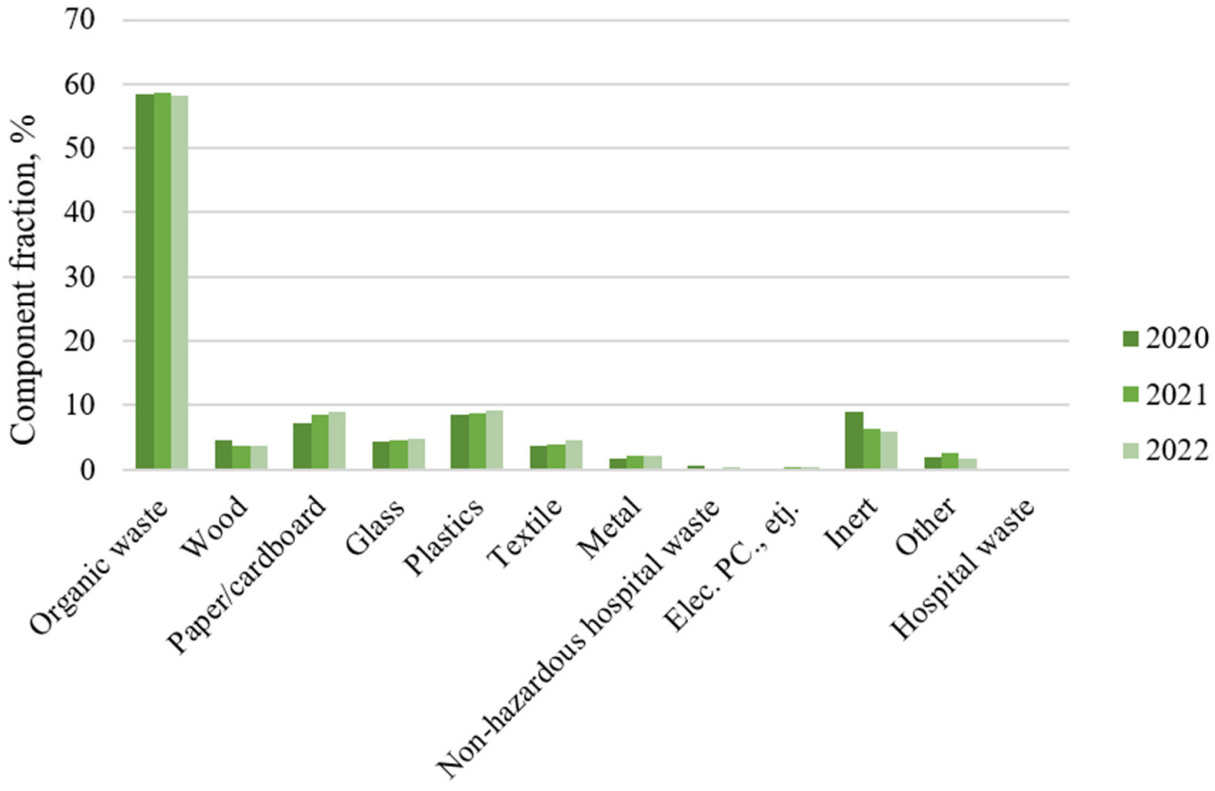

Figure 8. The composition of urban waste managed in the territory of Albania [33].

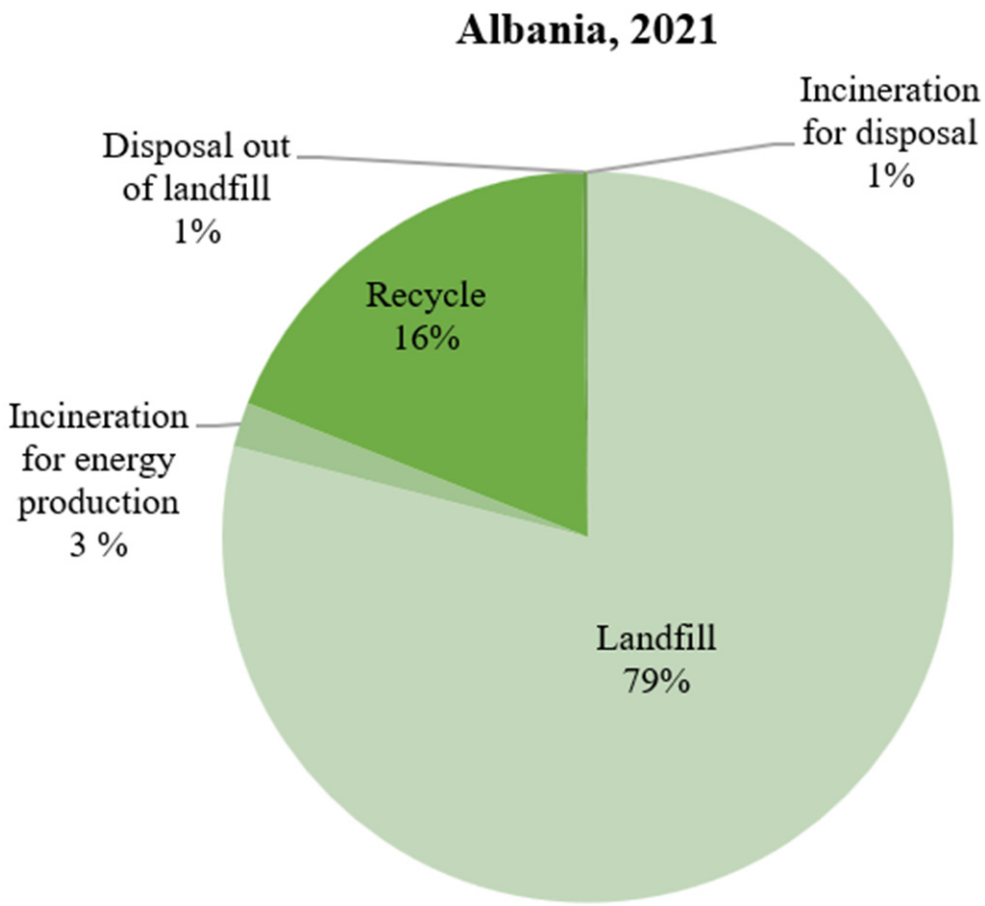

Figure 9. The treatment methods of urban solid wastes in Albania [33].

Regarding the composition of managed waste, their characteristics over the years are summarized in Figure 8. It is observed that they consist mostly of organic waste, followed by plastics, paper/cardboard, and inert materials. In smaller percentages are wood, glass, and textiles. Additionally, managed waste also includes some types deemed unsuitable for co-management with urban waste, such as non-hazardous electronic and hospital waste, which are fortunately reported in minimal quantities (less than 1%).

The extensive presence of various waste categories in landfills is an expression of the lack of segregated collection for these materials. From an energy recovery standpoint, this is a positive fact as these urban wastes hold significant potential for energy recuperation through biological, chemical, or incineration processes, generating combustible biomaterials and thermal/electric energy (owing to their high organic composition). Alternatively, there are no positive outcomes for the recycling sector. The data show that the content of organic waste, wood, and inert materials has decreased from 2020 to 2022. Meanwhile, there has been a slight increase in the presence of paper, glass, plastic, and textiles. This indicates that more recyclable waste is being discharged into the environment, around 24% of the total waste in 2022, worsening the fulfillment conditions of the hierarchy measures for solid waste management and resulting in financial setbacks for the local recycling sector.

In fact, according to the data from INSTAT, waste management in Albania does not entirely adhere to the waste management hierarchy. Approximately 79% of waste is deposited in landfills, 19% is recycled, and only 2% is incinerated for energy. Meanwhile, in Europe, around 31% of waste is recycled, approximately 44% is incinerated or composted, and only 23% is landfilled, with the aim of further reducing the latest one [34].

The data indicate that Albania possesses sufficient recycling capacity.

According to the EEA (European Environment Agency) report in 2019 [35], the Albanian Recyclers Association consists of 32 private recycling companies in Albania, with a

processing capacity of approximately 498,480 tons per year. Due to the lack of raw material, only 26.8% of this capacity is presently being utilized. With a capacity remaining untapped at 364,888 tons per year, it demonstrates the potential to process roughly 288,381 tons per year of recyclable waste that currently finds its way to landfills (Table 2).

Table 2. Recycling industry in Albania [24].

Year	Number of Recycling Companies	Installed Capacity (t/y)	Productivity (t/y)	Unused Capacity, (t/y)	Recyclable Waste in Landfill (t/y)
2019	32	498,480	133,592	364,888	288,381

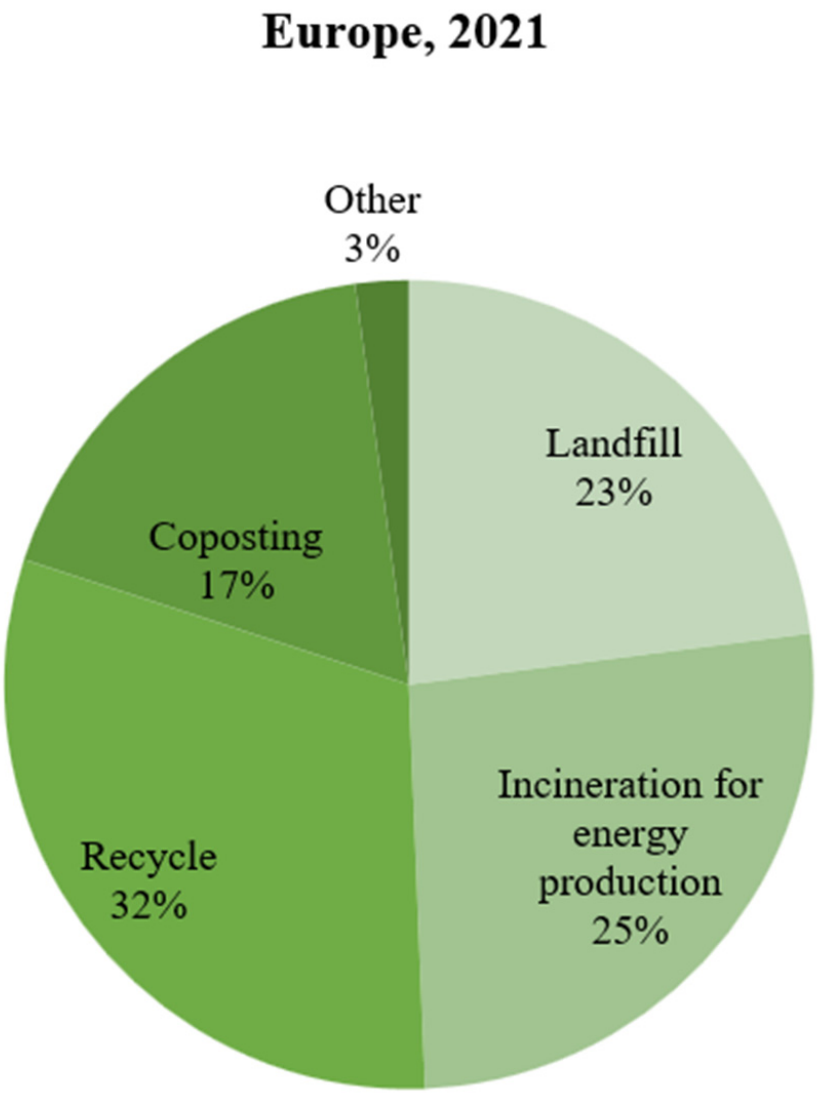

Figure 10. The treatment methods of urban solid wastes in Europe [36].

3.5. Albania's Approach to Waste-to-Energy Conversion Methods

Essentially, energy derived from waste is acquired using three primary methods: thermal and thermochemical treatment, biological treatment, and chemical treatment (Figure 11). In the processes of thermal and thermochemical treatment, combustion, gasification, and pyrolysis are involved. Biological treatment encompasses aerobic biodegradation, anaerobic biodegradation, composting, and fermentation. Meanwhile, chemical

treatment involves transesterification. The most commonly used processes for treating solid waste are thermal and biological. Systems based on these treatment types are thermal technologies, biological technologies, and controlled landfills. The products obtained from these processes are energy (electric or thermal), combustible materials (liquids: bio-alcohols, etc.; gases: biomethane), and useful chemicals for other industries.

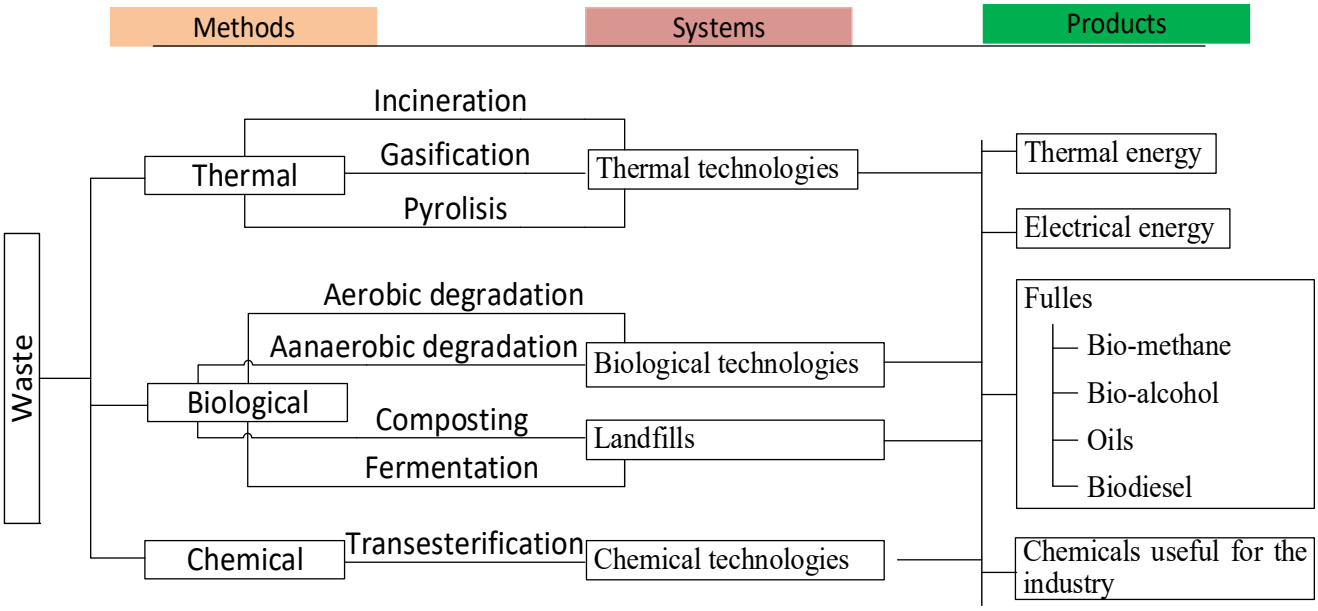

Figure 11. The methods of waste treatment in general.

One of the fundamental questions arising when discussing waste-to-energy conversion is which technology would be the most suitable. Choosing the most appropriate one is not simple and is based on several factors, including energy linked with the technology (amount of waste, quality of waste, and sustainability of waste supply); the environment (plant location and discharge management); social and political factors (public health and safety and governmental initiatives and desires); and economics (waste and electricity management, financial support, capital costs, revenue streams, and carbon credits). In Albania's context, notably, decision making is difficult because of the limited understanding of the qualitative and quantitative aspects of waste, coupled with the unreliability of reported data. As previously mentioned, our knowledge about waste is restricted primarily to the general quantities produced, their broad types, and their composition. Yet, for a comprehensive assessment, it is imperative to consider the basic chemical composition and several physical characteristics as well.

However, currently, Albania utilizes the method of waste incineration for energy production, treating only 2% of the waste. There is currently only one incineration plant in Elbasan, with a capacity of 43,800 t/y waste, and plans are underway for two more plants, one in Tirana and another in Fier, with an added capacity of 321,200 t/y waste (Table 3).

Table 3. Waste incinerator facilities in Albania.

Incinerator	Status	Capacity, t/y Waste
Elbasan	Functioning	43,800
Fier	Under construction	58,400
Tiranë	Under Construction	262,800

4. Conclusions

This study has provided a comprehensive assessment of Albania's journey toward optimizing its utilization of renewable energy sources derived from urban waste, guided by data-driven strategies. We have observed a significant paradigm shift in viewing waste not merely as an environmental burden but as a valuable resource for energy production. The adoption of waste-to-energy conversion technologies, classified as "Recovery" in the waste management hierarchy, holds immense potential for addressing environmental concerns while meeting energy demands. Our analysis underscores the correlation between legislative efforts and on-ground implementation in Albania's waste management landscape. Despite notable advancements in legislative alignment with EU standards, our findings reveal persistent challenges in translating regulations into effective practices. Alarmingly, landfilling remains the predominant method of waste disposal, comprising an exceptionally high percentage of 79%, while recycling and incineration occupy a mere 19% and 2%, respectively. Furthermore, our examination of the numerical data highlights critical gaps in waste recycling infrastructure and regulatory oversight. Only 26.8% of the installed annual capacity for waste recycling is currently utilized, resulting in an estimated annual landfill overflow of recyclable waste amounting to 288,381 tons. This divergence underscores the urgent need for improved waste collection mechanisms and enhanced monitoring practices. In the context of recovery, our study identifies significant potential for the integration of waste-to-energy technologies in Albania. With organic matter constituting approximately 58% of waste material, there exists a viable opportunity for energy production and the manufacturing of combustible substances. However, the low utilization rate of existing waste incineration facilities, currently treating only 2% of waste, underscores the imperative for further exploration of alternative methods such as plasma gasification and composting. Aligned with our research objectives, our findings emphasize the pressing need for concerted action to bridge the gap between legislation and practice, enhance waste recycling infrastructure, and explore innovative solutions for waste-to-energy conversion. By addressing these challenges, Albania can position itself as a frontrunner in sustainable waste management practices and renewable energy utilization, contributing to both environmental protection and energy security.

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