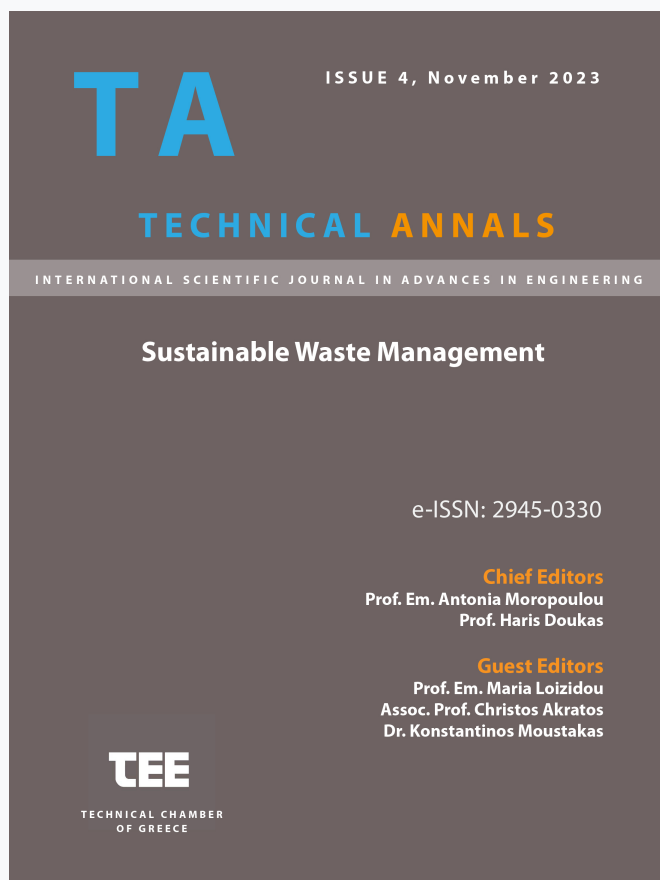


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Analyzing the Greek Legal Framework on Waste Management within the Circular Economy Context: Lessons learnt and lessons from EU Best Practices

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Abstract. The shift towards a circular economy is an essential goal of contemporary environmental policy, focusing on reducing waste generation, enhancing resource efficiency, and encouraging sustainable growth. This paper examines waste management approaches in the context of the national circular economy strategy, emphasizing regulatory structures, technological progress, and optimal methods for waste prevention, reuse, and recycling. Important policy tools, including extended producer responsibility (EPR), economic instruments, such as DRS and Pay as you Throw, as well as eco-design guidelines, and market incentives for recycled materials, are analyzed for their effectiveness and efficiency in minimizing environmental effects. The study additionally evaluates the impact of digital tools, data-informed decision-making, and cutting-edge waste treatment methods, such as mechanical-biological treatment (MBT), anaerobic digestion, and chemical recycling. Additionally, it addresses the socio-economic effects of moving to circular waste management systems, emphasizing the significance of involving stakeholders, raising public awareness, and fostering industry partnerships. Through the analysis of case studies and national progress indicators, this research uncovers obstacles and possibilities for enhancing waste management practices in accordance with circular economy principles. Results show that cohesive policy frameworks, investment in infrastructure, and shifts in behavior among consumers and businesses are crucial for realizing long-term sustainability objectives. The study concludes by providing strategic suggestions for policymakers, businesses, and researchers to enhance waste valorization, increase resource efficiency, and speed up the national circular economy transition. These insights enhance the overall comprehension of waste management as a crucial facilitator of a sustainable and resilient economy.

Keywords: Circular Economy, Waste Management, Resource efficiency, Re-use and Recycling, Extended Producer Responsibility (EPR)

1 Introduction

The shift towards a circular economy signifies a significant change in environmental policy, seeking to minimize waste, improve resource efficiency, and promote economic

sustainability [1]. In contrast to the conventional linear economic model—founded on the "take, make, dispose" approach—the circular economy emphasizes closed-loop systems that involve continual reuse, refurbishment, or recycling of materials and products [2]. This model corresponds with the wider sustainability aims of the European Union (EU), as detailed in the European Green Deal and the Circular Economy Action Plan (CEAP) 2020, which highlight waste reduction, eco-friendly design, and separating economic growth from resource use [3,4].

As a member state of the EU, Greece has worked to harmonize its waste management policies with European directives, especially by incorporating the Waste Framework Directive (2008/98/EC), as amended, the Landfill Directive (1999/31/EC), and the Packaging and Packaging Waste Directive (94/62/EC) into its national laws [5,6,7]. The implementation of Law 4819/2021 and the National Waste Management Plan (NWMP) 2020–2030 demonstrates Greece's dedication to meeting EU waste reduction goals and advancing principles of a circular economy [8,9]. These actions involve improving separate waste collection, applying Extended Producer Responsibility (EPR) programs, and limiting single-use plastics [10].

Nonetheless, in spite of these legal progressions, considerable obstacles persist in achieving effective execution. Greece still displays one of the highest reliance rates on landfills in the EU, as more than 75% of its municipal waste ends up in landfills—significantly higher than the EU average of 23.4% [11,12]. Recycling rates continue to be low, affected by poor waste separation at the origin, insufficient investment in advanced waste management facilities, and a lack of public awareness [13,14, 15]. Additionally, regional differences in waste management capabilities worsen these issues, as islands and rural regions find it difficult to adhere to EU waste regulations [16].

Analyzing Greece's waste management approaches alongside best practices from top EU countries exposes significant policy deficiencies. Member States like Germany, the Netherlands, and Sweden have effectively adopted high-performance circular economy models by enforcing strict landfill prohibitions, utilizing sophisticated digital waste monitoring systems, and providing economic incentives for material recovery [17,18]. Germany, for example, has reached a recycling rate surpassing 67% by implementing extensive EPR policies and utilizing Pay-As-You-Throw (PAYT) programs, which economically encourage households to reduce waste [19,20]. The Netherlands has launched industrial symbiosis initiatives via its Circular Economy Program 2050, promoting businesses to use each other's waste as raw materials [21]. Through the implementation of comparable strategies, Greece could improve its waste management effectiveness and hasten its shift towards a sustainable circular economy.

This paper rigorously analyzes Greece's waste management legal framework, examining its compliance with EU directives and pinpointing systemic obstacles that impede its efficiency. Through the examination of effective patterns from other EU countries, this study seeks to offer data-driven policy suggestions to strengthen Greece's regulatory framework, upgrade waste management infrastructure, and promote a more robust circular economy.

2 Legal Framework on Waste Management in Greece

Greece's legal framework for waste management is mainly influenced by EU law, especially the Waste Framework Directive (Directive 2008/98/EC) and the Circular Economy Action Plan (European Commission, 2020). These instruments create a legal framework for sustainable waste management by focusing on waste reduction, re-use, recycling, and efficient resource use.

Three critical regulatory mechanisms governing waste management at the EU and national levels are the Extended Producer Responsibility (EPR), the Eco-Design Regulations, and the Waste Treatment Hierarchy Compliance. These frameworks ensure that producers and consumers take responsibility for minimizing waste generation, enhancing product sustainability, and complying with EU waste reduction targets.

At the national level, Greece has integrated these policies via legislative actions such as Law 4819/2021, the National Waste Management Plan (NWMP) for 2020–2030, and rules that implement the circular economy concept. Such rules are enshrined in the Greek National Plan on Circular Economy which outlines a strategic framework aimed at transitioning the country's economic model from a linear to a circular paradigm, promoting sustainable development and resource efficiency. It foresees 71 actions and initiatives covering the full spectrum of circular economy including all the waste streams concerned. Rooted in the principles of reducing waste, reusing materials, and recycling resources, the plan emphasizes the integration of circular economy practices across key sectors, including agriculture, manufacturing, construction, and tourism. It aligns with the European Green Deal and the EU Circular Economy Action Plan, setting ambitious targets for reducing environmental impacts, enhancing competitiveness, and fostering innovation. The plan also focuses on legislative reforms, incentives for green investments, public-private partnerships, and awareness-raising initiatives to support systemic change. By embedding circular economy principles in national policy, Greece aims to improve environmental performance, strengthen economic resilience, and contribute to climate neutrality goals.

The main tools of the Greek policy and legal framework consist of:

2.1 The Extended Producer Responsibility (EPR):

The Extended Producer Responsibility (EPR) is an environmental policy framework that shifts the responsibility of waste management from municipalities to producers. It mandates that producers manage their products throughout their entire life cycle, including post-consumer waste collection, recycling, and disposal [22]. The main objectives of EPR is to enhance waste collection and recycling rates by requiring producers to establish or finance waste management systems, to promote eco-design by incentivizing manufacturers to produce more durable, repairable, and recyclable products [23], to reduce landfill dependency by ensuring proper waste segregation, treatment, and recovery of materials [24] and to implement the "polluter pays" principle, making producers accountable for the environmental impact of their products [25]. The OECD framework on EPR defines it as a policy instrument that extends a producer's responsibility beyond production and sale to post-consumer waste management (OECD, 2016).

The legal foundation of EPR in the EU is primarily based on:

- The Waste Framework Directive (Directive 2008/98/EC, as amended) – Establishes the principles of EPR and mandates that member states implement policies requiring producers to manage post-consumer waste [25]
- The Packaging and Packaging Waste Directive (Directive 94/62/EC, amended by Directive (EU) 2018/852) – Requires manufacturers to take financial and operational responsibility for the collection, sorting, and recycling of packaging materials [26]
- The Directive 2012/19/EU on Waste Electrical and Electronic Equipment (WEEE Directive) – Imposes recycling obligations on producers of electrical and electronic goods [27]
- The Directive 2000/53/EC on End-of-Life Vehicles (ELV Directive) – Regulates the collection and recycling of vehicles, ensuring proper disposal of hazardous waste [28]

Greece has incorporated EPR principles into its national framework through Law 4819/2021, mandating producer responsibility in packaging, electronics, batteries, and end-of-life vehicles [29]. However, implementation challenges persist due to weak enforcement mechanisms, lack of financial incentives for producers, and inadequate monitoring systems [30]. Compared to Germany and France, which have well-developed EPR programs with strict compliance monitoring, Greece struggles with producer non-compliance and inefficient collection systems [31].

2.2 The Eco-Design Legal Framework

Eco-design regulations refer to legislative measures aimed at improving the sustainability of products throughout their life cycle. These regulations mandate energy efficiency, resource conservation, and recyclability standards in product design, ensuring that manufacturers minimize environmental impact [32].

The EU has developed comprehensive legislation to enforce eco-design principles, primarily through:

- Eco-Design Directive (Directive 2009/125/EC) – Establishes minimum environmental standards for energy-related products, reducing their energy consumption and environmental footprint [33]
- EU Circular Economy Action Plan (COM/2020/98) – Promotes sustainable product design, durability, and repairability, focusing on extending product lifecycles and reducing waste generation [34]
- Directive 2018/851 amending the Waste Framework Directive – Requires waste prevention measures in product design, prioritizing reuse, repair, and recyclability [35]
- Single-Use Plastics Directive (Directive (EU) 2019/904) – Imposes design restrictions on plastic products, banning non-recyclable single-use plastics [36]

Greece has transposed the Eco-Design Directive into national law, requiring manufacturers to comply with EU energy efficiency and recyclability criteria [37]. However, enforcement remains weak, with low compliance rates among Greek manufacturers

compared to countries like Sweden and Denmark [38]. Key challenges include the lack of financial incentives for companies to adopt eco-friendly designs, the weak market surveillance mechanisms, resulting in non-compliant products and the limited consumer awareness regarding sustainable product choices [39].

2.3 Waste Treatment Hierarchy Compliance

The waste treatment hierarchy is a legally binding principle that dictates the preferred order of waste management strategies, ensuring that waste prevention, reuse, and recycling take precedence over landfill disposal [40]. The hierarchy prioritizes the Prevention – Avoiding waste generation, the Reuse – Extending the life of products and materials, the Recycling – Processing materials into new products, the Energy Recovery – Converting non-recyclable waste into energy and the Disposal (Landfill/Incineration) – The least preferred option [41].

The EU has established a strong legislative foundation for waste hierarchy compliance through:

- the Waste Framework Directive (2008/98/EC, Article 4) – Legally enforces the waste treatment hierarchy and obliges member states to prioritize waste prevention and recycling [42].
- the Landfill Directive (1999/31/EC) – Restricts landfilling of biodegradable municipal waste and mandates pre-treatment of waste before disposal [43].
- the Revised EU Waste Targets (Directive 2018/851) – Establishes recycling targets: 55% by 2025, 60% by 2030, and 65% by 2035 [44].
- the EU Circular Economy Package (2018) – Introduces restrictions on landfill usage and requires separate waste collection systems [45].

Greece continues to struggle with landfill dependency, with 75% of municipal waste still being landfilled, far exceeding the EU average of 23.4% [46]. Compliance failures have led to multiple EU infringement cases against Greece due to illegal landfill operations and poor waste management infrastructure [47].

Although there is a detailed legislative framework, considerable obstacles remain in the successful implementation of waste management policies in Greece. Administrative inefficiencies continue to be a significant obstacle, frequently associated with bureaucratic fragmentation, insufficient cooperation between national and local authorities, and uneven regulatory enforcement [48]. Research indicates that a lack of enforcement measures leads to significant non-compliance, especially in areas where obligations for waste separation and recycling are inadequately supervised [49]. Moreover, the restricted public knowledge and involvement in sustainable waste management practices impede the effectiveness of policy initiatives. Studies show that public engagement in recycling initiatives is minimal because of insufficient information sharing and the lack of incentives encouraging waste minimization and appropriate disposal [50]. This problem is worsened by infrastructure shortcomings, including a lack of recycling facilities and poor waste collection systems, which further restrict the effectiveness of waste reduction strategies [51]. Tackling these implementation gaps necessitates a comprehensive strategy, incorporating improved regulatory supervision, investment in waste management facilities, and focused educational initiatives to boost public engagement [52].

Enhancing governance systems and guaranteeing the efficient distribution of EU funds may significantly contribute to addressing these challenges and fulfilling Greece's circular economy goals [53].



Fig.1. The figure is visualizing the key challenges in Greece's waste management implementation. It highlights the severity of administrative inefficiencies, enforcement gaps, public awareness issues, and infrastructure deficiencies, based on recent studies and EU reports [54, 55, 56, 57]

3 EU Best Practices in Waste Management

To identify effective strategies for enhancing Greece's waste management system, this article analyzes successful initiatives implemented by EU member states, focusing on best practices in policy frameworks, innovative recycling technologies, circular economy approaches, and community-driven sustainability programs:

- Germany's Dual System (Duales System Deutschland, DSD) is an EPR-based waste collection and recycling scheme that has significantly enhanced packaging waste recovery and minimized landfill dependency. Under this system, producers and retailers finance the collection, sorting, and recycling of packaging waste through the Green Dot (Der Grüne Punkt) licensing fee, which incentivizes eco-friendly packaging design [58].
The system operates alongside municipal waste collection services, ensuring separate collection streams for recyclables, organics, and residual waste. Since its introduction in the 1990s, the recycling rate for packaging waste in Germany has surpassed 70%, one of the highest in Europe [59]. The success of this model lies in market-driven mechanisms, competitive waste management companies, and strict government oversight [60]. However, challenges such as over-complexity in sorting, contamination of recycling streams, and increasing plastic waste volumes require continuous adaptation [61]. Lessons for Greece include

the adoption of EPR schemes for packaging, enhanced consumer participation in source separation, and improved waste-sorting infrastructure.

- Sweden's Waste-to-Energy Model: Near-Zero Landfilling. Sweden is globally recognized for its highly advanced Waste-to-Energy (WtE) system, which enables the country to achieve near-zero landfill dependency [62]. Approximately 99% of Sweden's municipal waste is either recycled or used for energy recovery, with only 1% ending up in landfills [63]. This success is attributed to a well-integrated waste hierarchy, where non-recyclable waste is converted into electricity and district heating through state-of-the-art incineration plants [64]. Sweden's WtE incinerators use advanced flue gas treatment technologies, reducing harmful emissions while maximizing energy recovery efficiency. The country also imports waste from neighboring countries, such as Norway and the UK, demonstrating the economic viability of WtE solutions [65]. However, critics argue that over-reliance on incineration can discourage higher waste prevention and recycling rates [66].

For Greece, where landfill dependency remains high (~80%), investing in modern WtE facilities (gasification or pyrolysis), combined with strict waste sorting policies, could significantly reduce waste volumes while producing renewable energy.

- The Netherlands has established itself as a leader in circular economy initiatives, focusing on waste prevention, material recovery, and industrial symbiosis (10). The Dutch government has set an ambitious goal of achieving a 50% reduction in primary raw material consumption by 2030 and transitioning to a fully circular economy by 2050 [67].

Key strategies include the Mandatory Extended Producer Responsibility (EPR) schemes for packaging, electronics, and textiles, the High landfill taxation and bans on landfilling recyclable materials to promote reuse and recycling [68], the Material recovery hubs in industrial zones, where waste from one industry serves as input for another (industrial symbiosis) [69], the consumer awareness programs and sustainable product design incentives to foster responsible consumption [70]. The Netherlands has also been pioneering chemical recycling, which breaks down plastics into their molecular components, enabling higher-quality recycling outcomes [71].

Greece can learn from the Dutch approach by strengthening EPR laws, imposing landfill restrictions, promoting industrial symbiosis, and investing in chemical recycling technologies to maximize material recovery rates.

The waste management strategies employed by Germany, Sweden, and the Netherlands demonstrate how policy-driven initiatives can enhance recycling, material recovery, and landfill diversion rates. Greece can benefit from:

- Germany's EPR-based Dual System, focusing on producer responsibility for packaging waste.
- Sweden's Waste-to-Energy model, as an alternative to landfilling residual waste.

- The Netherlands' Circular Economy strategy, promoting material recovery, industrial symbiosis, and waste prevention.

By integrating these best practices, Greece can align with EU waste directives, improve waste treatment infrastructure, and move towards circular economy.

4 Waste Management Process, Economic Tools, Extended Producer Responsibility and Separate Collection at Source

Effective waste management is a critical component of sustainable development and environmental protection. The integration of systematic waste processing methods, economic instruments, producer responsibility policies, and efficient waste separation can significantly enhance recycling rates, resource recovery, and waste diversion from landfills. This chapter explores the waste management process, the role of economic tools, the effectiveness of Extended Producer Responsibility (EPR), and the importance of separate collection at source as fundamental strategies for improving municipal and industrial waste management.

4.1 Waste Management Process

The waste management process involves the systematic handling of waste from its generation to its final disposal or recovery. According to the Waste Hierarchy Framework, this process follows a priority order: prevention, reuse, recycling, recovery (including energy recovery), and disposal [72]. Proper waste management ensures the minimization of environmental impacts, the conservation of natural resources, and the reduction of greenhouse gas emissions associated with landfilling [73].

The key stages in the waste management process include:

- Waste generation and collection: Households, industries, and commercial activities generate different types of waste, requiring tailored collection systems [74]
- Transportation and sorting: Collected waste is transported to sorting facilities where recyclables are separated from residual waste [75]
- Recycling and recovery: Separated materials undergo processing to be reintegrated into production cycles, while non-recyclable waste may be used for energy recovery [76]
- Final disposal: Residual waste that cannot be recycled or recovered is sent to landfills or incineration plants with strict environmental controls [77]

Despite advancements in waste treatment technologies, challenges such as low source separation rates, infrastructure deficiencies, and illegal dumping remain significant obstacles in many countries, including Greece [78].

4.2 Key Economic Tools in Waste Management: A Pathway to Sustainability

Economic tools play a fundamental role in shaping waste management policies, influencing waste generation behaviors, and driving circular economy principles. By integrating pricing mechanisms, fiscal policies, and market-based incentives,

governments can internalize the environmental costs of waste and encourage resource-efficient practices [79]. These instruments promote waste prevention, increase recycling rates, and reduce landfill dependency, ultimately leading to financially sustainable waste management systems [80].

4.2.1 Landfill Taxes and Bans

Landfill taxes are one of the most effective policy tools for **reducing waste disposal in landfills** and promoting **higher recycling and recovery rates**. The European Commission has emphasized the role of landfill taxation in shifting waste away from landfills towards more sustainable treatment options [81].

Sweden and the Netherlands have landfill bans on recyclable materials and impose taxes exceeding €100 per tonne of landfilled waste [82].

The United Kingdom introduced a landfill tax in 1996, increasing it progressively to £96.70 per tonne in 2021, leading to an 85% reduction in municipal waste sent to landfills between 1996 and 2020 [83].

Greece, with landfill taxes around €20 per tonne, still struggles with high landfill dependency (~80%), demonstrating that higher tax rates are necessary to achieve significant reductions [84].

4.2.2 Deposit-Refund Systems (DRS): A Legal and Policy Perspective on Circular Economy Implementation

Deposit-refund systems (DRS) represent a market-based environmental policy instrument designed to promote the circular economy and extended producer responsibility (EPR) by encouraging the return of beverage containers for recycling. These systems function by imposing an upfront deposit on packaging, which is refunded to consumers upon the return of the container to designated collection points [85].

The legal foundation of DRS in the European Union (EU) is embedded within the Waste Framework Directive (2008/98/EC) and the Single-Use Plastics Directive (2019/904), which mandate increased collection targets for plastic beverage containers and encourage EPR-based financial responsibility for producers [86]. The EU Circular Economy Action Plan (2020) further supports DRS as a proven mechanism for achieving high collection and recycling rates, thereby reducing littering, conserving resources, and improving waste separation at source [87].

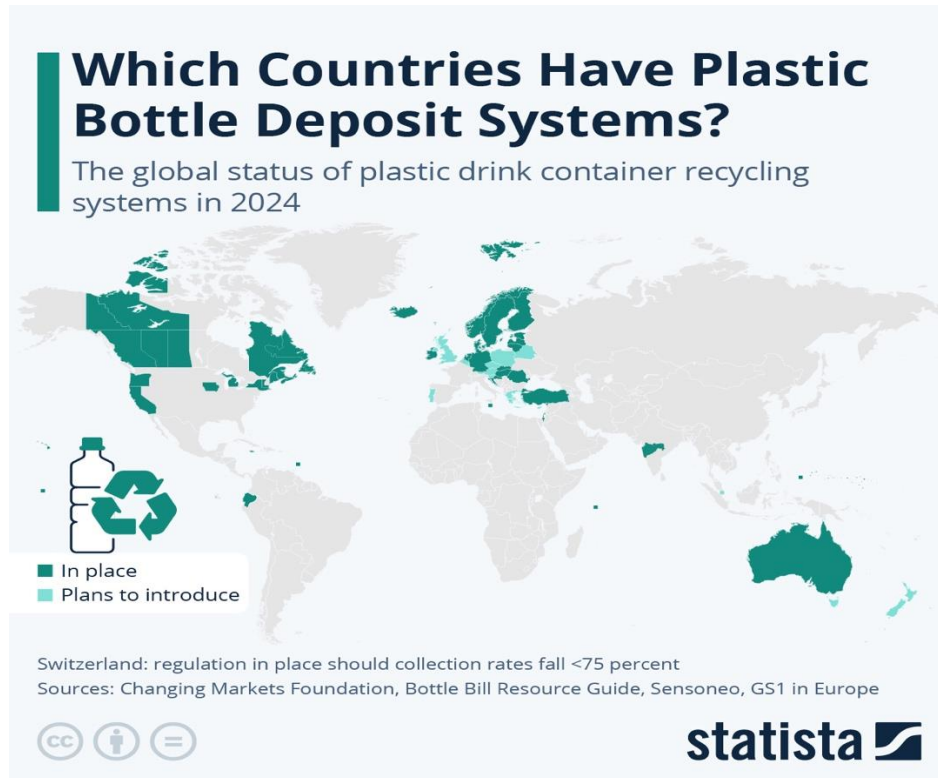


Fig.2. [88]

Despite EU-wide policy recommendations, DRS adoption remains uneven across member states, with significant variations in system design, financial responsibility, and collection infrastructure [89].

Germany operates one of the most legally structured and efficient DRS models in the EU, introduced under the Packaging Act (Verpackungsgesetz, 2019), which mandates a refundable deposit on single-use plastic and aluminum beverage containers [90]. Key legal provisions include:

- A mandatory deposit (€0.25 per container) for all PET bottles and aluminum cans
- A nationwide return infrastructure of reverse vending machines in supermarkets, ensuring accessibility for consumers
- Producer obligations under EPR laws, requiring beverage manufacturers to finance and operate collection systems [91]

The legal structure of Germany's DRS has resulted in a 98% return rate, effectively eliminating beverage container waste from public spaces and ensuring high-quality material recovery [92].

Lithuania introduced a nationwide DRS in 2016 under the Lithuanian Packaging Waste Management Regulations, aligning with the EU's EPR and circular economy requirements [93]. The system includes:

- A deposit of €0.10 per beverage container, covering PET, aluminum, and glass bottles
- The legal obligation for retailers to accept all returned containers, improving consumer participation
- Full financial responsibility on producers, ensuring the economic sustainability of the system

Following implementation, Lithuania's beverage container return rate surged from 34% to 92% within two years, demonstrating the effectiveness of legally enforced producer responsibility mechanisms [94].

Norway operates a unique, industry-led DRS system, regulated under the Pollution Control Act (1981) and the Waste Regulations (2004). Unlike other EU systems, Norway's DRS is voluntary but financially incentivized, where:

- Producers finance and operate the system, with state oversight ensuring compliance.
- A tiered taxation model provides tax exemptions for high collection rates, incentivizing producers to maximize returns [95].
- The system achieves return rates exceeding 95%, showcasing the efficiency of self-regulated industry-driven EPR frameworks [96].

Greece currently lacks a mandatory national DRS, relying primarily on municipal collection systems, which yield low beverage container recycling rates (~50%) [97]. The Waste Management National Plan (2020-2030) and Greece's alignment with EU Circular Economy goals necessitate the introduction of a comprehensive, legally binding DRS.

The key legal and policy considerations for Greece include:

- Amending national packaging legislation to mandate a deposit on all single-use beverage containers in compliance with Directive 2019/904/EU
- Establishing industry-funded collection systems, placing financial responsibility on producers and retailers under an EPR framework
- Introducing legal penalties for non-compliance to ensure retailers and producers participate in the system
- Creating a standardized return infrastructure to ensure consumer accessibility

Evidence from Germany, Lithuania, and Norway suggests that a well-structured legal framework with clear producer obligations, financial incentives, and enforcement mechanisms can significantly enhance beverage container recycling rates, reduce illegal waste disposal, and align Greece with EU waste reduction targets [98].

Deposit-refund systems have emerged as a legally effective tool for circular economy implementation, supported by EU waste regulations and national EPR frameworks. Case studies from Germany, Lithuania, and Norway demonstrate that clear

legislative structures, strong producer responsibility mandates, and financial incentives are essential to the success of a high-performance DRS.

For Greece, establishing a nationally regulated, producer-funded DRS in line with EU waste directives would increase recycling rates, improve material recovery, and reduce littering, contributing to a more circular and sustainable waste management system.

4.2.3 Pay-As-You-Throw (PAYT): A Legal and Policy Analysis in Waste Management

Pay-As-You-Throw (PAYT), also referred to as variable-rate pricing or unit-based pricing, is a waste management policy that charges households and businesses based on the actual amount of waste they dispose of. This system operates under the "polluter pays principle" (PPP) outlined in the EU Waste Framework Directive (2008/98/EC), which mandates that waste generators bear the financial cost of waste disposal [99].

PAYT is recognized as a market-based environmental instrument that aligns with circular economy principles by internalizing the external costs of waste disposal, reducing waste generation, and incentivizing higher recycling rates [100].

At the EU level, the Circular Economy Action Plan (2020) promotes PAYT as an effective waste prevention tool, encouraging member states to adopt PAYT models to comply with landfill diversion targets under the Landfill Directive (1999/31/EC) [101]. PAYT systems are legally structured through municipal ordinances, national waste laws, and extended producer responsibility (EPR) policies, making them a critical regulatory tool for achieving waste reduction goals [102].

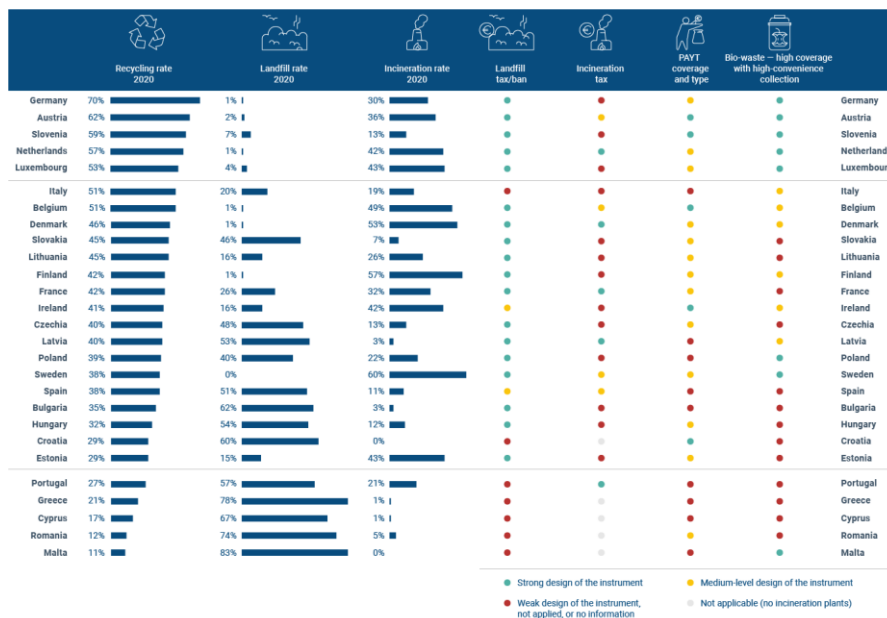


Fig.3. Recycling, landfill and incineration rates for municipal waste and key policy instruments used [103]

Among the EU States Belgium and Switzerland are developing success practices in PAYT implementation.

Belgium and Switzerland have implemented national PAYT frameworks, integrating the system within local waste management laws and municipal tax structures [104].

Belgium's Waste Decree (2012) legally mandates municipalities to implement PAYT schemes in compliance with EU waste hierarchy principles, resulting in a 40% reduction in municipal solid waste (MSW) generation and an increase in recycling rates [105].

Switzerland's Waste Management Act (2000) enforces PAYT at the municipal level, using prepaid waste bags and volume-based pricing. This policy has successfully reduced residual waste generation by nearly 50%, while ensuring high participation in source-separated recycling schemes [106].

Cyprus has undertaken several initiatives:

- Stakeholder Engagement: Regular meetings between the Ministry of Agriculture, Rural Development, and Environment, the Union of Municipalities, and the Union of Communities have been established to devise actionable plans for PAYT rollout [107]
- Pilot Programs: Municipalities such as Aglantzia have initiated pilot PAYT schemes to assess feasibility and gather data for broader application [108]
- Public Awareness Campaigns: Educational programs are being developed to inform citizens about the benefits of PAYT and encourage participation in waste sorting and reduction efforts.

The successful implementation of PAYT in Cyprus is expected to enhance Recycling Rates: Encourage citizens to sort waste effectively, thereby increasing recycling percentages, reduce Landfill Usage: Decrease the volume of waste directed to landfills, aligning with EU waste reduction targets and foster Environmental Responsibility: Promote a culture of sustainability and environmental stewardship among residents. By overcoming current challenges and leveraging legislative support, Cyprus aims to achieve a more sustainable and efficient waste management system through the PAYT initiative.

These cases demonstrate that mandatory legislative backing, coupled with strict enforcement and municipal oversight, is essential for PAYT effectiveness.

Greece generates approximately 500 kg of waste per capita annually, yet only 20% of waste is recycled, with the remaining 80% largely landfilled (13). Despite alignment with EU waste directives, Greece has not yet established a comprehensive national PAYT framework, relying primarily on fixed-rate municipal waste fees [109].

To effectively introduce PAYT, Greece must address several legal and policy challenges:

- Amending national waste legislation (e.g., Law 4042/2012, transposing the EU Waste Framework Directive) to mandate PAYT at the municipal level
- Incentivizing municipalities to adopt PAYT through financial grants and EU funding mechanisms
- Strengthening enforcement mechanisms to prevent illegal waste disposal resulting from PAYT cost avoidance

- Integrating PAYT with Extended Producer Responsibility (EPR) for packaging waste to offset implementation costs [110]

The success of PAYT in Belgium, Switzerland and Cyprus illustrates that clear legal frameworks, strong enforcement, and economic incentives are critical to ensuring the system's effectiveness. Greece's high waste generation and low recycling rates suggest that PAYT adoption could be a transformative policy, significantly improving waste separation at source, reducing landfill dependency, and lowering municipal waste management costs [111].

PAYT is a legally backed economic instrument that promotes waste reduction, recycling, and cost efficiency in municipal waste management. Case studies from Belgium, Switzerland and Cyprus show that legislative mandates, municipal enforcement, and technological innovations are key to successful PAYT implementation.

For Greece, introducing a PAYT-based national waste pricing policy could enhance compliance with EU waste directives, improve recycling rates, and reduce landfill dependency, contributing to a more sustainable waste management system.

4.2.4 Subsidies and Incentives for Sustainable Waste Management

Governments use subsidies and financial incentives to support circular economy initiatives, develop waste treatment infrastructure, and stimulate recycling industries [112].

France provides financial aid for recycling innovation, including tax incentives for companies adopting eco-design principles [113].

The EU's Horizon 2020 program allocates billions to waste management research and pilot projects, fostering circular economy solutions [114].

In Sweden, subsidies for biogas production from food waste have increased anaerobic digestion plant numbers, reducing organic waste landfilling by over 60% [115].

For Greece, increasing investment in waste-to-energy, biowaste treatment, and material recovery technologies through financial incentives is essential to modernizing its waste management system [116].

Economic tools such as landfill taxes, DRS, PAYT schemes, and targeted subsidies have proven to be effective policy instruments for improving waste management efficiency. Countries that implement these economic instruments achieve higher recycling rates, lower waste generation per capita, and reduced landfill dependency. For Greece, adopting a combination of PAYT, DRS, landfill taxation, and financial incentives will be crucial in transitioning towards a circular economy and sustainable waste management system.

5 Challenges and Opportunities in Greece's Circular Economy Transition

The circular economy aims to minimize waste generation, optimize resource efficiency, and close material loops through sustainable production and consumption patterns. While Greece has made legislative progress in aligning with EU circular

economy policies, the country continues to face significant implementation barriers in transitioning from a linear to a circular waste management system. Despite these challenges, strategic policy adjustments, infrastructure investments, and enhanced stakeholder collaboration offer opportunities for advancing circular economy practices in Greece.

5.1 Challenges in Implementing Circular Waste Management in Greece

5.1.1 Regulatory Gaps: Weak Enforcement and Policy Inconsistencies

Although Greece has transposed key EU waste management directives such as the Waste Framework Directive (2008/98/EC) and the Circular Economy Action Plan (2020) into national law, weak enforcement and inconsistencies in policy application hinder effective implementation [117].

Lack of enforcement mechanisms results in high non-compliance rates among businesses and municipalities, particularly in waste separation and landfill diversion targets [118].

Greece continues to struggle with illegal dumping and poor landfill management, despite the EU Landfill Directive (1999/31/EC), which requires waste minimization and controlled disposal [119].

Regional disparities in regulatory oversight lead to inconsistent waste management standards across municipalities, affecting the efficiency of circular economy initiatives [120].

A stronger governance framework, including increased inspections, stricter penalties, and digital monitoring of waste streams, is crucial for ensuring compliance with EU circular economy goals.

5.1.2 Infrastructure Deficiencies: Limited Facilities for Advanced Waste Treatment

Greece's waste management infrastructure remains underdeveloped, limiting the country's ability to process, recycle, and recover materials efficiently [121].

Lack of material recovery facilities (MRFs) and modern waste treatment plants results in low recycling rates (~20%) compared to the EU average of 48% [122].

Limited anaerobic digestion and composting facilities restrict the potential for bio-waste valorization, leading to high organic waste landfilling (~65% of municipal waste) [123].

Poor integration of digital tracking systems for waste collection and sorting contributes to inefficiencies in waste logistics and contamination of recyclables [124].

Expanding recycling and biowaste treatment infrastructure, along with integrating waste-to-energy (WtE) technologies, would enhance circular economy performance by diverting waste from landfills and promoting material recovery.

5.1.3 Public Engagement Issues: Low Awareness and Participation

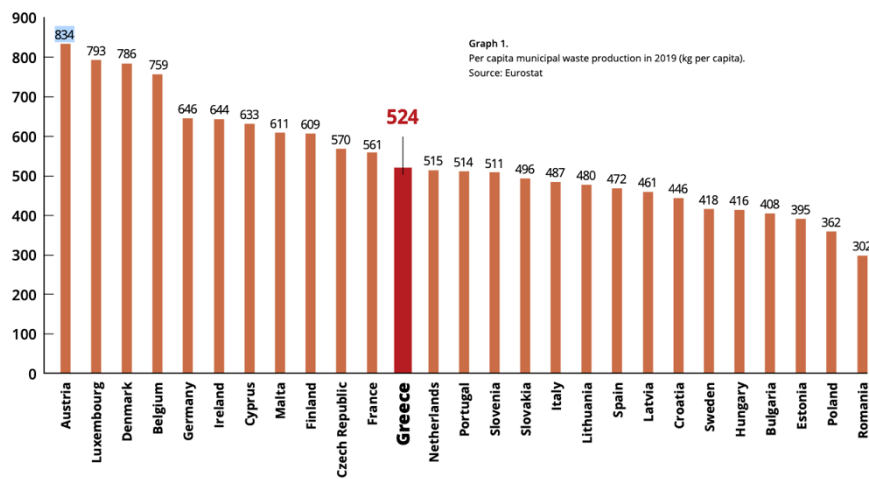
Public engagement is a critical enabler of circular economy success, yet low awareness and participation in Greece remain significant barriers [125].

Studies indicate that only 30% of Greek households regularly separate waste at source, compared to 70% in countries with mature recycling systems such as Germany and Sweden [126].

Limited environmental education programs and incentives for waste sorting reduce public motivation to participate in circular economy initiatives [127].

Consumer behavior trends favor single-use plastics, despite the EU Single-Use Plastics Directive (2019/904/EC) banning certain disposable items [128].

Increasing public awareness campaigns, deposit-return schemes (DRS), PAYT, and financial incentives could enhance participation in waste separation, recycling, and sustainable consumption behaviors.



1. Data from Eurostat. Recovery from [here](#).

2. There are serious doubts about the accuracy of the reported recycling rate in Greece, as the preparation for recycling does not necessarily translate into actual recycling. Moreover, the credibility of the data collected by the responsible authorities has been undermined. Recent [report](#) by the European Environment Agency shows that the actual recycling rate in Greece is not more than 16%.

Fig.4. Per capita municipal waste production in 2019 (kg per capita). Source: Eurostat [129],[103]

5.2 Opportunities for Advancing Circular Economy in Greece

5.2.1 Policy Refinement: Strengthening EPR Mechanisms and Market Incentives

The Extended Producer Responsibility (EPR) framework in Greece requires further strengthening to enhance market incentives for recycled materials and support circular product design [130].

Expanding EPR obligations to more product categories, such as textiles and electronics, could improve waste recovery rates [131].

Introducing tax incentives for circular businesses and eco-friendly packaging materials would drive investment in sustainable production models [132].

Harmonizing national recycling targets with EU directives, such as Directive 2018/851/EC, would ensure compliance with the EU Green Deal objectives [133].

5.2.2 Investment in Infrastructure: Expanding and upgrading Recycling and Waste Treatment Facilities

EU Cohesion and Recovery Funds offer an opportunity to invest in circular economy infrastructure, addressing long-standing deficiencies [134].

Allocating EU recovery funds (€5 billion by 2030) toward advanced waste treatment plants and recycling hubs can improve waste recovery efficiency [135].

Expanding biowaste treatment capacity through composting and anaerobic digestion plants would reduce organic waste landfilling [136].

Adopting AI-powered waste sorting technologies can increase the purity of recyclable materials and reduce contamination rates [137].

5.2.3 Stakeholder Collaboration: Encouraging Industry and Community Engagement

A multi-stakeholder approach involving government agencies, industries, and local communities is crucial for Greece's circular economy transition [138].

Industry partnerships with waste management firms and research institutions can drive eco-innovation [139].

Community-led circular economy initiatives can improve local recycling participation and waste prevention [140].

Cross-border cooperation with EU partners can facilitate knowledge transfer and investment in circular solutions [141].

While regulatory gaps, infrastructure deficiencies, and low public engagement present challenges, policy refinement, strategic investments, and stakeholder collaboration offer pathways to accelerate Greece's circular economy transition. Strengthening EPR frameworks, expanding waste treatment capacity, and enhancing public participation will be key to achieving sustainable waste management and resource efficiency goals.

6 Conclusion and Policy Recommendations

To achieve a fully functional circular economy, Greece must implement cohesive policy frameworks, enhance infrastructure investments, and encourage behavioral changes among consumers and businesses. Addressing existing challenges in waste management and resource efficiency is crucial for long-term sustainability. Based on the analysis, the following recommendations are proposed:

- Strengthen Extended Producer Responsibility (EPR) Implementation:
 - Boost the implementation of the Greek National Plan on Circular economy through the implementation by joint ministerial decisions of all the 71 actions and initiatives it foresees.
 - Enforce stricter accountability measures for producers to minimize waste generation, ensuring compliance with the EU Waste Framework Directive (2008/98/EC) and the Circular Economy Action Plan [142].

Encourage eco-design initiatives to ensure products are reusable and recyclable. Studies show that improved product design can reduce material waste by up to 30% [143].

Monitor and evaluate EPR compliance to enhance effectiveness, leveraging data from the European Environment Agency (EEA, 2023). Research indicates that countries with well-implemented EPR schemes have achieved packaging waste recycling rates above 60%, while Greece remains at 54.1% [144].

- Enhance Technological Adoption:

Invest in digital tools such as AI-driven waste sorting systems and smart recycling bins, which can increase sorting efficiency by 40% [145].

Upgrade waste treatment infrastructure, including modern material recovery facilities (MRFs) and anaerobic digestion plants, to address Greece's current low recycling rate of approximately 20%, compared to the EU average of 48% [146]. Countries with advanced waste treatment facilities, such as Germany and the Netherlands, have achieved over 65% recycling rates [147].

Support research and innovation in circular economy technologies, allocating funds through EU programs such as Horizon Europe, which has earmarked €10 billion for green innovation [148]. Reports suggest that every €1 billion invested in circular economy initiatives generates approximately 50,000 new jobs [149].

- Promote Public Awareness Campaigns:

Launch nationwide educational initiatives to inform citizens about waste reduction and recycling best practices. Surveys indicate that only 30% of Greek households consistently separate waste at the source, compared to 70% in countries like Germany and Sweden [150]. A study in Sweden found that strong public awareness programs contributed to their 99% municipal waste recovery rate [151].

Develop incentive programs, such as deposit-return schemes (DRS), which have increased plastic bottle recycling rates to over 90% in countries where implemented, such as Germany [152]. In contrast, Greece's plastic bottle recycling rate stands at approximately 30% [153].

Collaborate with schools, businesses, and local communities to increase engagement in sustainability efforts, using successful case studies from other EU member states. For example, Belgium's "Fost Plus" system has led to a 95% recycling rate for household packaging waste.

- Encourage Cross-Sector Collaboration:

Establish partnerships between government, industry, and research institutions to develop sustainable waste management solutions, as seen in Finland's "Circular Economy Roadmap" [154]. Finland's collaboration model has helped achieve a 55% circular material use rate, compared to Greece's 3.1%.

Facilitate knowledge sharing through circular economy networks and best practice exchanges, aligning with EU Circular Economy Stakeholder Platform initiatives. Studies show that knowledge-sharing platforms increase adoption rates of circular economy practices by up to 40%.

Promote circular business models, such as product-as-a-service (PaaS) and industrial symbiosis, which have been shown to increase resource efficiency by up

to 50% in industrial sectors [155]. Reports suggest that transitioning to circular business models could add €1.8 trillion to the European economy by 2030.

By adopting these strategies, Greece can accelerate its transition towards circular economy. A concerted effort by policymakers, businesses, and the public will be essential in achieving long-term environmental and economic benefits. Implementation of these policies could result in a 25% reduction in landfill dependency and a 15% increase in material recovery rates by 2030 [160]. Additionally, a well-implemented circular economy framework could boost Greece's GDP by up to 2% and create over 50,000 green jobs by 2035 [156].

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