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"Strategic, Financial and Environmental Assessment of a Potential Waste-to-Energy Plant in the Region of Peloponnese: Lessons from the European Union"

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Patras, Greece, May 2026

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"This one is for me"

Abstract

This dissertation examines the strategic, financial, and environmental feasibility of developing a medium-scale Waste-to-Energy (WtE) facility in Southern Greece, with a service area covering the Region of Peloponnese, Western Greece, and the Ionian Islands (excluding Corfu). The study addresses the increasing need for sustainable residual waste management solutions in alignment with the European Union's Circular Economy Action Plan and landfill reduction targets.

The research adopts a quantitative case study approach, integrating Cost–Benefit Analysis (CBA), financial modeling (NPV, IRR), Multi-Criteria Decision Analysis (MCDA), and strategic tools such as PESTEL and SWOT analysis. Waste flow projections are derived from existing Mechanical Biological Treatment facilities and population-based estimates, resulting in an annual feedstock of approximately 121,742 tonnes.

Energy modeling indicates that the proposed facility can generate approximately 89 GWh of electricity annually. The inclusion of Combined Heat and Power (CHP) and district heating significantly enhances performance, increasing total energy efficiency and generating additional revenues of approximately €4.4 million per year. Financial analysis shows that while the project is marginally viable under electricity-only operation, CHP integration transforms it into a financially robust investment, with a positive Net Present Value and improved Internal Rate of Return.

Environmental assessment demonstrates that the facility could reduce greenhouse gas emissions by 36,000–73,000 tonnes of CO_2 equivalent annually, primarily through methane avoidance and fossil fuel displacement. Comparative analysis with Germany, Sweden, and Italy highlights the importance of governance stability, energy integration, and public acceptance.

The study concludes that the proposed WtE facility in Megalopolis represents a strategically aligned and economically viable investment, provided that strong policy frameworks, long-term contracts, and CHP integration are implemented.

Keywords

Waste-to-Energy (WtE); Circular Economy; Combined Heat and Power (CHP); Municipal Solid Waste (MSW); Cost–Benefit Analysis (CBA); District Heating

Περίληψη

Η παρούσα διπλωματική εργασία εξετάζει τη στρατηγική, χρηματοοικονομική και περιβαλλοντική σκοπιμότητα ανάπτυξης μίας μονάδας Ενεργειακής Αξιοποίησης Αποβλήτων (Waste-to-Energy – WtE) μεσαίας κλίμακας στη Νότια Ελλάδα, με περιοχή εξυπηρέτησης την Περιφέρεια Πελοποννήσου, τη Δυτική Ελλάδα και τα Ιόνια Νησιά (πλην Κέρκυρας). Η μελέτη ανταποκρίνεται στην αυξανόμενη ανάγκη για βιώσιμες λύσεις διαχείρισης υπολειμματικών αποβλήτων, σε ευθυγράμμιση με το Σχέδιο Δράσης της Ευρωπαϊκής Ένωσης για την Κυκλική Οικονομία και τους στόχους περιορισμού της υγειονομικής ταφής.

Η έρευνα υιοθετεί μία ποσοτική προσέγγιση μελέτης περίπτωσης, ενσωματώνοντας Ανάλυση Κόστους–Οφέλους (Cost–Benefit Analysis – CBA), χρηματοοικονομική μοντελοποίηση (NPV, IRR), Πολυκριτηριακή Ανάλυση Αποφάσεων (Multi-Criteria Decision Analysis – MCDA), καθώς και στρατηγικά εργαλεία όπως οι αναλύσεις PESTEL και SWOT. Οι προβλέψεις ροών αποβλήτων βασίζονται σε υφιστάμενες εγκαταστάσεις Μηχανικής Βιολογικής Επεξεργασίας (MBT/MEA) και σε εκτιμήσεις πληθυσμιακών δεδομένων, οδηγώντας σε ετήσια τροφοδοσία περίπου 121.742 τόνων.

Η ενεργειακή μοντελοποίηση δείχνει ότι η προτεινόμενη εγκατάσταση μπορεί να παράγει περίπου 89 GWh ηλεκτρικής ενέργειας ετησίως. Η ενσωμάτωση Συμπαραγωγής Ηλεκτρισμού και Θερμότητας (Combined Heat and Power – CHP) και συστημάτων τηλεθέρμανσης βελτιώνει σημαντικά την απόδοση της μονάδας, αυξάνοντας τη συνολική ενεργειακή αποδοτικότητα και δημιουργώντας επιπλέον έσοδα περίπου €4,4 εκατομμυρίων ετησίως. Η χρηματοοικονομική ανάλυση καταδεικνύει ότι, ενώ το έργο εμφανίζεται οριακά βιώσιμο σε λειτουργία αποκλειστικής ηλεκτροπαραγωγής, η ενσωμάτωση CHP το μετατρέπει σε μία οικονομικά ισχυρή επένδυση, με θετική Καθαρή Παρούσα Αξία (Net Present Value – NPV) και βελτιωμένο Εσωτερικό Βαθμό Απόδοσης (Internal Rate of Return – IRR).

Η περιβαλλοντική αξιολόγηση δείχνει ότι η εγκατάσταση θα μπορούσε να μειώσει τις εκπομπές αερίων του θερμοκηπίου κατά 36.000–73.000 τόνους ισοδυνάμου CO_2 ετησίως, κυρίως μέσω της αποφυγής εκπομπών μεθανίου από χώρους υγειονομικής ταφής και της

υποκατάστασης ορυκτών καυσίμων. Η συγκριτική ανάλυση με τη Γερμανία, τη Σουηδία και την Ιταλία αναδεικνύει τη σημασία της θεσμικής σταθερότητας, της ενεργειακής ενσωμάτωσης και της κοινωνικής αποδοχής.

Η μελέτη καταλήγει στο συμπέρασμα ότι η προτεινόμενη μονάδα WtE στη Μεγαλόπολη αποτελεί μία στρατηγικά ευθυγραμμισμένη και οικονομικά βιώσιμη επένδυση, υπό την προϋπόθεση εφαρμογής σταθερών πολιτικών πλαισίων, μακροχρόνιων συμβάσεων και ενσωμάτωσης τεχνολογιών CHP.

Λέξεις – Κλειδιά

Ενεργειακή Αξιοποίηση Αποβλήτων (WtE); Κυκλική Οικονομία; Συμπαραγωγή Ηλεκτρισμού και Θερμότητας (CHP); Αστικά Στερεά Απόβλητα (MSW); Ανάλυση Κόστους–Οφέλους (CBA); Τηλεθέρμανση

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List of Abbreviations & Acronyms

Abbreviation	Definition
BAT	Best Available Techniques
CBA	Cost–Benefit Analysis
CE	Circular Economy
CEAP	Circular Economy Action Plan
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DCF	Discounted Cash Flow
EEA	European Environment Agency
EU	European Union
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
LHV	Lower Heating Value
MCDA	Multi-Criteria Decision Analysis
MBT	Mechanical Biological Treatment
MSW	Municipal Solid Waste
NPV	Net Present Value
OPEX	Operating Expenditure
CAPEX	Capital Expenditure
PPP	Public–Private Partnership
RDF	Refuse-Derived Fuel
SRF	Solid Recovered Fuel
WtE	Waste-to-Energy

1. Introduction

1.1 Background and Context of Waste Management in Greece

Municipal solid waste (MSW) management in Greece has historically been characterized by a strong dependence on landfill disposal. Despite gradual improvements in recycling rates over the past decade, landfill remains the dominant treatment pathway compared to leading European Union (EU) Member States (European Commission, 2020). According to EU waste statistics, Greece continues to face structural challenges in diverting biodegradable and residual waste streams away from landfill, thereby risking non-compliance with European targets (European Environment Agency [EEA], 2022).

The European Union has progressively strengthened its waste governance framework through Directive 2008/98/EC (Waste Framework Directive), which establishes the waste hierarchy, prioritizing prevention, reuse, recycling, recovery, and finally disposal (European Parliament & Council, 2008). The Circular Economy Action Plan (CEAP) further reinforces this framework by promoting material efficiency and reducing reliance on landfill as a long-term disposal strategy (European Commission, 2020).

Greece's National Waste Management Plan (2020–2030) recognizes energy recovery as a complementary solution for residual fractions that cannot be recycled economically or technically. In this context, Waste-to-Energy (WtE) infrastructure emerges as a transitional instrument aimed at reducing landfill dependency while ensuring controlled treatment of non-recyclable waste.

1.2 Role of Waste-to-Energy in Sustainable Development

Waste-to-Energy refers to the thermal treatment of residual waste for the purpose of energy recovery, typically through electricity and, in some cases, heat production. Modern WtE facilities operate under strict environmental standards defined by the Industrial Emissions Directive (2010/75/EU), including continuous emissions monitoring and Best Available Techniques (BAT) requirements (European Parliament & Council, 2010; European Commission, 2019).

From a sustainability perspective, WtE may contribute to three main objectives::

1. Landfill diversion and methane avoidance
2. Energy recovery and fossil fuel displacement
3. Controlled management of residual waste streams

Empirical evidence from mature EU waste systems demonstrates that WtE can coexist with high recycling rates when clearly positioned as residual treatment rather than as a substitute for material recovery (Brunner & Rechberger, 2015). For example, Germany and Sweden have achieved both high recycling performance and significant WtE capacity, illustrating that energy recovery can function as a complementary component within the waste hierarchy (Scarlat et al., 2019).

From a climate perspective, the diversion of biodegradable waste from landfill reduces methane emissions, a greenhouse gas with significantly higher global warming potential than carbon dioxide over a 100-year horizon (IPCC, 2021). When coupled with displacement of marginal fossil-based electricity generation, WtE can generate measurable net greenhouse gas mitigation benefits under system-level analysis.

1.3 Waste Management Challenges in the Peloponnese, Western Greece, and the Ionian Islands

The Region of Peloponnese has developed several Mechanical Biological Treatment (MBT/MEA) facilities, including installations in Paliochouni (Arcadia), Kalliroi (Messinia), Skala (Laconia), and Triantafyllia (Ilia). While these facilities enhance sorting and stabilization processes, residual fractions remain substantial, ranging approximately between 39% and 45% depending on facility configuration and waste composition.

In parallel, Western Greece and the Ionian Islands (excluding Corfu) face structural constraints in advanced residual waste valorization capacity. The absence of large-scale energy recovery infrastructure in Southern Greece results in continued reliance on landfill or interregional transport solutions.

The projected landfill reduction target below 10% of municipal waste by 2035 (European Parliament & Council, 2018 amendment to Directive 2008/98/EC) intensifies the need for alternative residual treatment solutions. Consequently, the development of a regional WtE facility may serve as a structural mechanism to stabilize the waste management system across multiple regions.

1.4 Research Rationale and Contribution

While policy discussions at national level have referenced the potential role of WtE in achieving landfill diversion targets, there is limited integrated analysis combining:

- Strategic positioning
- Financial viability
- Environmental performance
- Spatial optimization
- European benchmarking

The dissertation attempts to address this gap through a combined strategic and financial assessment of a potential medium-scale WtE facility serving the Peloponnese, Western Greece, and the Ionian Islands (excluding Corfu). Unlike purely technical feasibility studies, this dissertation integrates strategic management tools, financial modeling, and policy evaluation within an MBA analytical framework.

The research therefore contributes to decision-making at both regional and investment levels by evaluating not only technical feasibility but also economic sustainability and policy coherence.

1.5 Research Objectives, Questions, and Hypotheses

The primary objective of this dissertation is to assess whether a medium-scale Waste-to-Energy facility in Southern Greece is strategically justified, financially viable, and environmentally beneficial.

The study is structured around the following research questions:

1. Is there sufficient residual waste volume to sustain a medium-scale WtE plant in Southern Greece?
2. Is the proposed investment financially viable under realistic gate fee and electricity price assumptions?
3. Does the project generate net environmental benefit compared to continued landfill disposal?
4. Which spatial location provides optimal operational and strategic conditions?
5. What lessons from mature EU WtE markets are transferable to the Greek context?

The underlying working hypothesis is that a properly structured WtE facility, integrated within the waste hierarchy and supported by stable contractual frameworks, can represent a viable transitional infrastructure supporting Greece's landfill reduction pathway.

1.6 Structure of the Dissertation

The dissertation is organized as follows:

- Chapter 2 reviews relevant literature on circular economy principles, WtE technologies, environmental performance, and EU regulatory frameworks.
- Chapter 3 outlines the methodological approach, including financial modeling, MCDA site selection, and scenario analysis.
- Chapter 4 presents the strategic, financial, and environmental assessment of the proposed facility.

- Chapter 5 benchmarks the Greek case against mature EU WtE systems.
- Chapter 6 synthesizes findings and provides strategic and policy recommendations.

Through this structured approach, the study develops an integrated decision-support framework for evaluating regional Waste-to-Energy investments within the European policy landscape.

2. Literature Review

2.1 Circular Economy Principles and Waste Valorization

The transition from a linear to a circular economic model represents one of the most significant paradigm shifts in contemporary environmental policy and resource management. The traditional linear model, characterized by a "take–make–dispose" approach, has been widely criticized for its inefficiency in resource utilization and its contribution to environmental degradation (Geissdoerfer et al., 2017). In contrast, the circular economy (CE) aims to maintain the value of materials, products, and resources for as long as possible while minimizing waste generation.

The European Commission (2020) defines the circular economy as a system that promotes sustainable production and consumption patterns through resource efficiency, reuse, recycling, and recovery. Within this framework, waste is no longer viewed as a liability but as a potential resource that can be reintegrated into the economic cycle.

The Waste Framework Directive (2008/98/EC) establishes the waste hierarchy as a fundamental principle guiding waste management policy. This hierarchy prioritizes:

1. Prevention
2. Reuse
3. Recycling
4. Recovery (including energy recovery)
5. Disposal

(European Parliament & Council, 2008)

Energy recovery, including Waste-to-Energy (WtE), is positioned below recycling but above landfill disposal. This positioning reflects the recognition that while material recovery is preferable, certain waste streams cannot be effectively recycled due to contamination, complexity, or economic constraints (Brunner & Rechberger, 2015).

Recent research emphasizes that even highly efficient recycling systems generate residual waste fractions ranging between 20% and 40% of total municipal waste (Kaza et al., 2018). These fractions often consist of composite materials, low-quality plastics, and contaminated organic waste that are unsuitable for recycling processes. As a result, WtE is increasingly viewed as a necessary component of integrated waste management systems.

Iacovidou et al. (2020) argue that optimizing waste-to-energy systems within a circular economy framework requires balancing material recovery with energy recovery, rather than treating them as competing alternatives. In practice, this means that waste management systems should be evaluated as integrated systems rather than as isolated treatment technologies.

2.2 Waste-to-Energy Technologies and System Configurations

Waste-to-Energy technologies encompass a range of thermal and thermochemical processes designed to convert waste into usable energy. Among these technologies, mass-burn incineration remains the most widely deployed solution for municipal solid waste in Europe due to its technological maturity and operational reliability (Scarlat et al., 2019).

2.2.1 Mass-Burn Incineration

Mass-burn incineration involves the direct combustion of mixed municipal waste on a moving grate system. This technology is capable of handling heterogeneous waste streams without extensive pre-treatment, making it suitable for large-scale applications.

Advantages include:

- High reliability and availability
- Ability to process mixed waste streams
- Proven environmental compliance under EU standards

However, limitations include:

- Moderate electrical efficiency (~20–25%)

- Dependence on waste composition (Arena, 2012)

2.2.2 Advanced Thermal Technologies: Gasification and Pyrolysis

Gasification and pyrolysis are advanced thermochemical processes that convert waste into syngas or bio-oil under controlled oxygen conditions. While these technologies offer potential advantages in terms of efficiency and emissions, their application in municipal waste management remains limited due to technical complexity and feedstock sensitivity (Arena, 2012).

Malkow (2004) highlights that these technologies require more homogeneous feedstock, typically in the form of RDF/SRF, which increases pre-treatment requirements and operational costs.

2.2.3 RDF and SRF Production

Refuse-Derived Fuel (RDF) and Solid Recovered Fuel (SRF) are produced through mechanical treatment processes that remove recyclable materials and enhance calorific value. These fuels improve combustion stability and energy output.

Typical calorific values:

- MSW: 7–10 MJ/kg
- RDF: 10–15 MJ/kg
- SRF: up to 18 MJ/kg

(European Commission, 2019)

The use of RDF/SRF is particularly relevant for improving the efficiency and economic performance of WtE plants.

2.3 Environmental Performance and Life Cycle Assessment

Environmental evaluation of WtE systems requires a life-cycle perspective that considers upstream and downstream impacts. Life Cycle Assessment (LCA) studies compare different waste management options, including landfill, recycling, and energy recovery.

Cherubini et al. (2009) demonstrate that WtE systems can achieve lower net greenhouse gas emissions than landfill disposal, primarily due to methane avoidance. Methane emissions from landfills represent a significant contributor to climate change due to their high global warming potential (IPCC, 2021).

Astrup et al. (2015) further highlight that WtE plants can provide net environmental benefits when:

- landfill gas capture is limited
- fossil-based electricity is displaced
- recycling is maximized prior to energy recovery

However, the environmental performance of WtE is influenced by several factors:

- waste composition (biogenic vs fossil carbon)
- energy efficiency
- emission control technologies
- system boundaries used in analysis

2.4 Economic and Financial Aspects of WtE Systems

WtE plants are characterized by high capital intensity and long operational lifetimes, making financial evaluation a critical component of project feasibility.

According to OECD (2018), capital costs for WtE plants typically range between €500 and €900 per annual tonne of capacity. Operating costs vary between €70 and €110 per tonne, depending on plant size and labor conditions.

Revenue streams include:

- Gate fees
- Electricity sales
- Heat sales (in CHP systems)

- By-product recovery (e.g., metals from ash)

Tomic and Schneider (2020) emphasize that gate fees represent the most stable revenue source, as they are typically secured through long-term municipal contracts. Electricity revenues, in contrast, are subject to market volatility.

The introduction of carbon pricing mechanisms can further influence financial performance. When carbon costs are internalized, WtE may become more competitive relative to landfill disposal (OECD, 2018).

2.5 European Policy Framework

The development of WtE infrastructure is strongly influenced by European policy instruments.

- **Waste Framework Directive**

The Waste Framework Directive establishes binding targets for recycling and landfill reduction (European Parliament & Council, 2008).

- **Industrial Emissions Directive**

The Industrial Emissions Directive ensures that WtE plants operate under strict environmental standards (European Parliament & Council, 2010).

- **Circular Economy Action Plan**

The CEAP promotes resource efficiency and sustainable waste management (European Commission, 2020).

- **Landfill Directive**

The Landfill Directive limits the disposal of biodegradable waste, indirectly supporting WtE development.

2.6 Case Studies and Comparative Evidence

- **Germany**

Germany has achieved near-zero landfill disposal of untreated waste through strict regulation and high recycling rates (Brunner & Rechberger, 2015).

- **Sweden**

Sweden demonstrates the integration of WtE into district heating systems, achieving high overall efficiency (Scarlat et al., 2019).

- **Italy**

Italy illustrates the importance of governance consistency, with significant regional disparities in infrastructure development (EEA, 2022).

2.7 Public Acceptance and Social Factors

Public acceptance is a critical factor influencing WtE deployment. Studies show that transparency, environmental monitoring, and stakeholder engagement significantly improve social acceptance (EEA, 2022).

Opposition often arises from:

- perceived health risks
- lack of trust in authorities
- historical environmental issues

Effective communication and governance are therefore essential.

2.8 Literature Gaps and Research Contribution

Despite extensive research, several gaps remain:

- Limited regional-level financial modeling
- Lack of integration between spatial analysis and financial evaluation
- Insufficient focus on Southern European contexts
- Limited analysis of Just Transition integration

This dissertation addresses these gaps by combining:

- financial modeling
- MCDA spatial analysis
- EU benchmarking
- policy evaluation

2.9 System Integration of Waste-to-Energy within Energy and Circular Economy Systems

The role of Waste-to-Energy (WtE) systems has evolved significantly over the past decades, transitioning from a waste disposal solution to an integrated component of modern energy and circular economy systems. In advanced economies, WtE facilities are increasingly conceptualized as multi-functional infrastructure nodes that simultaneously address waste management, energy production, and climate mitigation objectives (IEA Bioenergy, 2020).

Traditionally, WtE plants were designed primarily to reduce the volume of waste and minimize landfill dependence. However, this perspective has shifted toward a systems-based approach, where WtE is embedded within broader energy networks and resource efficiency strategies. This transition reflects a growing recognition that residual waste streams represent a continuous and predictable energy source that can contribute to energy system stability (Scarlat et al., 2019).

2.9.1 Integration with Energy Systems

One of the most significant developments in WtE deployment is its integration within national and regional energy systems. Unlike intermittent renewable energy sources such as wind and solar, WtE plants provide baseload energy, operating continuously and contributing to grid stability (IEA, 2021).

This characteristic is particularly important in energy systems undergoing decarbonization, where the increasing penetration of variable renewable energy sources creates challenges related to supply variability and grid balancing. In this context, WtE facilities can provide dispatchable power that complements renewable energy generation.

Furthermore, the energy recovery process in WtE plants can be optimized through Combined Heat and Power (CHP) configurations. CHP systems significantly increase overall energy efficiency by capturing and utilizing heat that would otherwise be lost in electricity-only generation processes. In electricity-only plants, efficiency typically ranges between 20% and 25%, whereas CHP systems can achieve total efficiencies exceeding 70% (European Commission, 2019).

The integration of WtE into district heating networks represents one of the most efficient applications of this technology. Countries such as Sweden, Denmark, and Germany have successfully implemented district heating systems that rely heavily on waste-derived heat. In Sweden, for example, WtE contributes significantly to urban heating demand, with some cities relying almost entirely on waste-based heat supply (Avfall Sverige, 2020).

2.9.2 District Heating and Urban Energy Planning

District heating systems enable the distribution of thermal energy from centralized plants to residential, commercial, and industrial consumers. When integrated with WtE facilities, these systems transform waste treatment plants into key components of urban energy infrastructure.

The economic and environmental benefits of district heating integration include:

- increased overall energy efficiency
- reduced dependence on fossil fuels for heating
- improved financial performance through additional revenue streams
- enhanced energy system resilience

Lund et al. (2014) argue that district heating systems are essential for achieving high levels of energy efficiency in urban environments, particularly when combined with waste-derived heat sources. The ability to utilize low-grade heat that would otherwise be wasted represents a significant advantage in terms of resource efficiency.

However, the implementation of district heating systems requires substantial infrastructure investment and long-term planning. The economic viability of such systems depends on factors including population density, industrial demand, and existing energy infrastructure.

In the context of Southern Greece, and particularly the Megalopolis region, the potential for district heating integration remains underexplored. The presence of existing energy infrastructure and industrial land creates favorable conditions for future development. If implemented, district heating could significantly enhance the economic viability of WtE projects, as demonstrated in Northern European case studies.

2.9.3 Industrial Symbiosis and Resource Efficiency

Beyond energy integration, WtE facilities can play a role in broader industrial symbiosis systems. Industrial symbiosis refers to the exchange of materials, energy, and by-products between different industrial processes in order to improve overall efficiency and reduce waste (Chertow, 2000).

WtE plants can contribute to such systems by:

- supplying heat to nearby industries
- recovering metals from bottom ash
- providing energy for industrial processes
- reducing the need for landfill space

The concept of eco-industrial parks incorporates WtE facilities as central nodes within industrial ecosystems. In such systems, waste from one process becomes input for another, creating closed-loop resource flows.

For example, bottom ash from WtE plants can be processed to recover metals and used as construction material, reducing the need for virgin resources (Astrup et al., 2015). This contributes to circular economy objectives by extending material lifecycles beyond initial use.

2.9.4 Carbon Policy and Emissions Considerations

The role of WtE in climate policy remains a subject of ongoing debate. While WtE reduces methane emissions from landfill and displaces fossil-based energy, it also generates carbon dioxide emissions from the combustion of fossil-derived waste fractions, particularly plastics.

The inclusion of WtE in carbon pricing mechanisms, such as the European Union Emissions Trading System (EU ETS), has been widely discussed. Some studies suggest that incorporating WtE into ETS frameworks could significantly affect the financial performance of such facilities by increasing operational costs (EEA, 2022).

However, it is important to distinguish between biogenic and fossil carbon emissions. A significant portion of municipal waste consists of biogenic materials, which are considered carbon-neutral under current accounting frameworks (IPCC, 2021). Therefore, the net climate impact of WtE depends on the composition of the waste stream.

Recent studies emphasize the importance of integrating carbon capture and storage (CCS) technologies with WtE plants. Carbon capture could significantly reduce emissions and potentially transform WtE facilities into negative emission systems when biogenic carbon is captured (IEA, 2021).

Although CCS is not yet widely deployed in WtE facilities, its future potential represents an important consideration for long-term strategic planning.

2.9.5 Critical Perspectives on Waste-to-Energy Integration

Despite the benefits associated with WtE systems, critical perspectives highlight several challenges and risks that must be considered.

A commonly discussed concern in the literature relates to possible infrastructure lock-in effects, where long-term investment in WtE infrastructure creates incentives to maintain waste generation levels in order to ensure plant utilization (Zaman, 2015). This could potentially conflict with circular economy objectives aimed at reducing waste generation.

Additionally, critics argue that WtE may compete with recycling if not properly regulated. High calorific value waste streams, particularly plastics, may be diverted to energy recovery instead of recycling, reducing material recovery rates.

However, empirical evidence from countries such as Germany suggests that strong policy frameworks can mitigate these risks. When recycling targets and landfill restrictions are strictly enforced, WtE functions as a complementary rather than competing technology (Brunner & Rechberger, 2015).

Another concern relates to public perception and social acceptance. Even when environmental performance meets regulatory standards, WtE projects may face opposition due to perceived health risks and environmental concerns. This highlights the importance of transparency, stakeholder engagement, and effective communication strategies.

2.9.6 Implications for the Greek Case Study

The integration of WtE within energy and circular economy systems has important implications for the Greek context. The proposed facility in Megalopolis has the potential to function not only as a waste treatment plant but also as an energy infrastructure asset.

The potential integration of district heating represents a particularly important opportunity. While such systems are not currently widespread in Greece, their development could significantly enhance both the environmental and economic performance of WtE projects.

Furthermore, the alignment of WtE with Just-Transition policies provides an additional strategic dimension. The redevelopment of former lignite regions creates opportunities for new energy infrastructure that supports decarbonization while maintaining economic activity.

However, successful implementation requires careful policy design to ensure that WtE complements rather than undermines recycling efforts. This includes:

- maintaining strong recycling targets
- regulating waste composition

- ensuring transparency in environmental performance
- designing flexible infrastructure capable of adapting to future waste reductions.

3.Methodology

3.1 Research Design and Philosophical Approach

This study adopts a **quantitative case study design** combined with structured comparative analysis. The research follows a **positivist analytical framework**, emphasizing measurable variables, financial modeling, and scenario-based evaluation (Saunders, Lewis, & Thornhill, 2019).

The case study focuses on a potential Waste-to-Energy (WtE) facility serving:

- The Region of Peloponnese
- Western Greece
- The Ionian Islands (excluding Corfu)

The analysis integrates:

- Secondary statistical data
- Policy documentation
- Financial modeling
- Multi-Criteria Decision Analysis (MCDA)
- Comparative EU benchmarking

This mixed analytical structure allows both investment appraisal and strategic positioning assessment.

3.2 Data Collection and Sources

The study relies exclusively on **secondary data sources**, including:

- National Waste Management Plan (2020–2030)
- EU Waste Framework Directive (2008/98/EC)
- Industrial Emissions Directive (2010/75/EU)
- European Commission BAT Reference Documents
- European Environment Agency (EEA) reports

- Facility design capacities of MBT/MEA plants in Southern Greece
- EU waste and landfill statistics

Projected residual waste volumes were derived from:

- Reported MEA facility capacities
- Residual percentage assumptions (39–45%)
- Population-based estimates for regions lacking advanced facilities

Where exact operational data were unavailable, conservative assumptions were applied to avoid overestimation of feedstock volumes.

3.3 Feedstock Estimation and Energy Potential Modeling

3.3.1 Residual Waste Volume Estimation

The projected annual feedstock to the WtE facility was estimated at:

$$Q = 121{,}742 \text{ tonnes/year}$$

This figure results from:

- Diversion of residual fractions from existing MBT facilities
- Estimated residual production from Western Greece and Ionian Islands (population-adjusted)
- Alignment with landfill reduction targets (<10%)

The study assumes progressive reduction of landfill disposal toward 2030, with WtE absorbing residual fractions exceeding landfill thresholds.

3.3.2 Lower Heating Value (LHV) Assumptions

The Lower Heating Value (LHV) of mixed residual waste was modeled under three scenarios:

- Conservative: 10 MJ/kg
- Base case: 12 MJ/kg
- Optimistic (RDF-enhanced): 15 MJ/kg

These values are consistent with European municipal residual waste literature (Scarlat et al., 2019).

3.3.3 Energy Output Calculation

Annual thermal energy input:

$$E_{thermal} = Q \times LHV$$

For base case:

$$121{,}742\ \text{t} \times 12\ \text{MJ/kg}$$

Converted to MWh:

$$1\ \text{MWh} = 3.6\ \text{GJ}$$

Electrical output was calculated assuming net efficiency:

$$\eta = 22\%$$

Resulting in:

$$E_{electric} \approx 89{,}000\ \text{MWh/year}$$

The final electricity generation estimate also considers:

- operational downtime,
- internal electricity consumption,
- and standard system losses.

The resulting electricity generation estimate (approximately 89 GWh/year) is subsequently used throughout the financial assessment presented in the following chapters.

3.3.4 Assumptions and Model Parameters

The accuracy and robustness of the analytical framework developed in this study depend significantly on the assumptions applied in estimating waste flows, energy recovery potential, and financial performance. Given the absence of complete real-time operational data for all regions included in the study, a structured and conservative assumptions framework was developed.

The assumptions applied are based on:

- published European benchmarks
- national waste management plans
- existing facility capacities
- academic literature
- engineering practice

The objective of this approach is to ensure that results are both realistic and reproducible, while avoiding overestimation of project performance.

3.3.4.1 Waste Flow Assumptions

- **Residual Waste Generation**

The core assumption of the model relates to the volume of residual waste available for treatment.

Residual waste is defined as the fraction of municipal solid waste (MSW) that remains after:

- source separation
- recycling
- composting
- mechanical treatment

Based on operational data from existing MBT/MEA facilities in the Peloponnese, residual fractions were assumed as:

- **45%** for Arcadia, Messinia, Laconia
- **39%** for Ilia and Achaia

These values reflect typical European performance ranges (EEA, 2022).

- **Future Waste Reduction Target**

In alignment with EU policy, the study assumes:

$$Landfill \leq 10\% \text{ by } 2030$$

This implies that a portion of residual waste currently directed to landfill must be diverted to alternative treatment solutions, including WtE.

Thus, the model assumes:

- **35% diversion** (for 45% residual systems)
- **29% diversion** (for 39% residual systems)

This reflects a realistic transition pathway rather than a full immediate shift.

- **Population-Based Estimates**

For regions without fully developed infrastructure (Western Greece, Ionian Islands excluding Corfu), waste generation was estimated using:

$$Waste = Population \times 450 \text{ kg/person/year}$$

This value is consistent with EU averages (World Bank, 2018).

Residual fraction assumed:

$$39\%$$

3.3.4.2 Feedstock Stability Assumption

The model assumes that sufficient waste supply contracts will ensure:

- stable annual feedstock
- minimal fluctuation (<±5%)
- long-term availability (20–25 years)

This assumption reflects European WtE practice, where municipalities guarantee waste volumes through contractual agreements (OECD, 2018).

3.3.4.3 Calorific Value (LHV) Assumptions

The Lower Heating Value (LHV) of waste is a critical parameter for energy calculations.

Three scenarios were used:

Scenario	LHV
Conservative	10 MJ/kg
Base Case	12 MJ/kg
Optimistic	15 MJ/kg

These values reflect typical European residual waste compositions (Scarlat et al., 2019).

The base-case value (12 MJ/kg) assumes moderate RDF/SRF contribution.

3.3.4.4 Energy Conversion Efficiency

Electrical efficiency is assumed at:

$$22\%$$

This reflects typical performance for electricity-only WtE plants.

For CHP scenarios:

- total efficiency >70%
- heat recovery efficiency assumed at 40% usable output

3.3.4.5 Operational Availability

The plant is assumed to operate:

$$8{,}000 \text{ hours/year}$$

This corresponds to:

- high availability (~90%)
- standard European WtE performance

(EEA, 2022)

3.4 Financial Modeling Framework

The technical and operational assumptions developed in the previous sections form the basis of the financial assessment presented below. In particular, feedstock availability, calorific value assumptions, and energy recovery performance directly influence the projected revenue structure and long-term economic viability of the proposed facility.

The financial feasibility of the proposed Waste-to-Energy (WtE) facility is evaluated using a structured Discounted Cash Flow (DCF) framework, which is widely applied in infrastructure investment appraisal (Brealey et al., 2020).

The financial model incorporates:

- capital expenditure (CAPEX)
- operating expenditure (OPEX)
- revenue streams (gate fees, electricity, heat)
- project lifetime
- discount rate
- sensitivity variables

The primary financial indicators used in this study are:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Payback Period

The core financial modelling auuptions are:

Parameter	Assumption
Annual Feedstock	121,742 tonnes/year
Plant Lifetime	25 years
Discount Rate	6%
Electricity Price	€105/MWh
Gate Fee	€80/t
Electrical Efficiency	22%
CHP Heat Utilization	40%
CAPEX	€110 million
OPEX	€90/t

Carbon Price Range	€70–93/tCO_2

3.4.1 Capital Expenditure (CAPEX) Assumptions

Capital expenditure represents the initial investment required for the construction and commissioning of the WtE facility.

Based on European benchmarks, WtE plant costs typically range between €500 and €900 per annual tonne of installed capacity (OECD, 2018). For the proposed facility, with a design capacity of approximately 120,000–130,000 tonnes per year, CAPEX is conservatively estimated at:

$$CAPEX = €110{,}000{,}000$$

This estimate includes:

- civil construction works
- combustion and boiler systems
- steam turbine and generator
- flue gas treatment systems (BAT compliant)
- grid connection infrastructure
- engineering, procurement, and construction (EPC) costs
- contingency allowance (~10–15%)

The assumption reflects a mid-range estimate to avoid underestimation of investment requirements.

3.4.2 Operating Expenditure (OPEX) Assumptions

Operating expenditure includes all recurring costs associated with plant operation.

European WtE facilities typically exhibit OPEX values between €80 and €120 per tonne (OECD, 2018). For this study, a base-case assumption of:

$$OPEX = €90/t$$

is applied.

Total annual operating cost is calculated as:

$$OPEX_{total} = Q \times 90$$

Where:

- $Q = 121{,}742$ tonnes/year

Thus:

$$OPEX_{total} \approx €10.96M/year$$

OPEX includes:

- labor and staffing
- maintenance and repairs
- consumables (chemicals, reagents)
- ash handling and disposal
- administrative costs

3.4.3 Revenue Streams

The financial viability of the project depends on multiple revenue sources.

3.4.3.1 Gate Fee Revenue

Gate fees represent payments made by municipalities for waste treatment services. They constitute the most stable and predictable revenue stream.

Base-case assumption:

$$Gate\ Fee = €80/t$$

Annual revenue:

$$R_{gate} = Q \times Gate\ Fee$$

$$R_{gate} \approx €9.74M/year$$

Sensitivity range:

$$€80–€95/t$$

This reflects both current Greek market conditions and European benchmarks.

3.4.3.2 Electricity Revenue

Electricity is generated through steam turbine conversion.

Annual electricity output:

$$E_{electric} \approx 89{,}278 \text{ MWh/year}$$

Base-case electricity price:

$$€105/MWh$$

Thus:

$$R_{electric} = 89{,}278 \times 105 \approx €9.37M/year$$

Sensitivity range:

$$€75–€150/MWh$$

This range accounts for market volatility and energy price fluctuations observed in European markets.

3.4.3.3 Heat Revenue (CHP Scenario)

A critical enhancement of the financial model is the inclusion of Combined Heat and Power (CHP).

Recoverable heat:

$$\approx 316{,}522 \text{ MWh/year}$$

Assuming 40% utilization:

$$Heat_{usable} \approx 126{,}600 \text{ MWh/year}$$

Heat price assumption:

$$€35/MWh$$

Thus:

$$R_{heat} \approx €4.43M/year$$

This additional revenue stream significantly improves project viability and aligns the system with high-efficiency European WtE models.

3.4.3.4 Ash Valorization and Metal Recovery

In addition to gate fee income and energy generation, the financial model also considers potential revenues associated with bottom ash valorization and metal recovery.

Modern Waste-to-Energy facilities increasingly integrate circular economy practices through:

- ferrous metal recovery,
- non-ferrous metal recovery,
- and secondary aggregate utilization from processed bottom ash.

Based on European operational benchmarks (Šyc et al., 2020; Bandarra et al., 2021), bottom ash generation was assumed at approximately 20–25% of incoming waste mass.

Assuming conservative material recovery and secondary aggregate utilization rates, additional annual revenues of approximately:

$$€0.5–0.6\ \text{M}/year$$

were estimated.

Although smaller than gate fee or CHP revenues, ash valorization improves:

- overall project resilience,
- resource efficiency,
- and circular economy integration.

In addition to improving project revenues, ash recovery practices also strengthen the circular economy dimension of the proposed facility by reducing landfill disposal requirements and supporting secondary material recovery.

3.4.4 Total Revenue and Cash Flow

Total annual revenue:

$$R_{total} = R_{gate} + R_{electric} + R_{he} \quad + R_{material}$$

$$R_{total} \approx €24.1M/year$$

Net operating cash flow:

$$CF = R_{total} - OPEX$$

$$CF \approx €13.1M/year$$

3.4.5 Net Present Value (NPV)

The Net Present Value is calculated as:

$$NPV = \sum_{t=1}^{25} \frac{CF}{(1+r)^t} - CAPEX$$

Where:

- $r = 6\%$ discount rate
- Project lifetime = 25 years

Thus:

$$NPV \approx €52 - 55$$

Using a CAPEX assumption of €110 million, annual net operating cash flow of approximately €13-14 million, a 25-year project lifetime, and a 6% discount rate, the estimated NPV is approximately €52-55 million. This positive result applies to the CHP-integrated scenario..

3.4.6 Internal Rate of Return (IRR)

The IRR represents the discount rate at which:

$$NPV = 0$$

For the base-case CHP scenario:

$$IRR \approx 10 - 11\%$$

This range is consistent with infrastructure investment expectations.

3.4.7 Payback Period

The payback period is estimated as:

$$Payback \approx \frac{CAPEX}{Annual\ Cash\ Flow}$$

$$\approx 8 - 9 \text{ years}$$

Based on the estimated CAPEX of €110 million and annual net operating cash flow of approximately €13-14 million, the simple payback period is approximately 8-9 years. When discounted cash flows are considered, the discounted payback period is estimated at approximately 11-13 years, depending on electricity price and heat utilization assumptions

3.4.8 Discount Rate Assumption

A discount rate of:

$$r = 6\%$$

is applied.

This reflects:

- infrastructure investment risk
- European benchmark rates (5–8%)
- relatively stable revenue structure

3.4.9 Financial Risk Considerations

Key risks include:

- gate fee variability
- electricity price volatility
- regulatory changes
- carbon pricing

The inclusion of CHP mitigates risk by diversifying revenue streams.

3.5 Sensitivity and Scenario Analysis

Sensitivity analysis was performed in order to evaluate how changes in key technical and economic assumptions may affect the financial performance of the proposed Waste-to-Energy (WtE) facility. Given the long operational lifetime of WtE infrastructure projects, investment outcomes are highly dependent on market conditions, waste composition, and energy recovery efficiency.

The analysis focused on several variables considered particularly important for project viability, including:

gate fee variation (±15%)
electricity price fluctuation (±30%)
heat utilization rates under CHP operation (30–50%)
Lower Heating Value (LHV) variability
potential carbon pricing mechanisms

Three principal scenarios were developed to assess the robustness of the investment model under different operating conditions.

3.5.1 Conservative Scenario

The conservative scenario assumes relatively unfavorable market and operational conditions, including:

- low electricity prices (approximately €75/MWh),
- lower calorific value waste streams,
- limited CHP utilization,
- and reduced revenues from material recovery (approximately €1.0–1.3M/year).

Under these assumptions, the project generates limited profitability and may produce a marginal or slightly negative Net Present Value (NPV), particularly if gate fees remain below projected levels.

3.5.2 Base-Case Scenario

The base-case scenario reflects moderate energy prices and average waste calorific values consistent with current European WtE benchmarks.

The scenario also assumes partial heat recovery through CHP integration and stable material recovery revenues (approximately €1.5–2.0M/year).

Under these conditions, the project produces:

- positive NPV,
- acceptable IRR,
- and stable long-term financial performance.

3.5.3 Optimistic Scenario

The optimistic scenario assumes:

- favorable electricity market conditions,
- improved waste calorific value,
- high utilization of recoverable heat through CHP applications,
- and strong market demand for recovered metals and ash-derived materials (approximately €2.0–2.5M/year).

In this case, the project demonstrates significantly improved profitability, stronger cash flow generation, and shorter payback periods.

3.5.4 Carbon Pricing Considerations

Potential future carbon pricing mechanisms were also considered in the analysis. Carbon prices in the range of approximately €70–93/tCO_2 may influence both operational costs and the relative competitiveness of Waste-to-Energy compared with landfill disposal.

Although the inclusion of WtE facilities within future EU carbon pricing frameworks remains uncertain, higher carbon prices could encourage improved waste sorting practices and increase pressure to reduce landfill dependency.

3.5.5 Conclusion of the Sensitivity Analysis

Overall, the results of the sensitivity analysis suggest that the financial performance of the proposed facility depends primarily on:

- gate fee stability,
- electricity market conditions,
- heat utilization through CHP integration,
- and material recovery revenues.

Among the variables examined, CHP utilization and material recovery appear to have the strongest positive effect on long-term project viability.

The methodology presented in this chapter was designed to support a multidimensional evaluation of the proposed Waste-to-Energy facility under the specific economic, environmental, and infrastructural conditions of Southern Greece.

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4.Strategic and Financial Assessment of the Proposed Waste-to-Energy Facility

4.1 Overview of the Proposed Waste-to-Energy Plant Design

The proposed facility is conceptualized as a medium-scale Waste-to-Energy (WtE) plant designed to treat residual municipal solid waste generated in Southern Greece. The plant would serve the Region of Peloponnese while also receiving residual waste streams from Western Greece and the Ionian Islands (excluding Corfu). This interregional structure enhances feedstock security and improves economies of scale for the facility.

Modern WtE plants convert residual municipal waste into electricity through controlled combustion processes, typically using moving-grate incineration technology due to its operational reliability and ability to process heterogeneous waste streams (Scarlat et al., 2019). This technology is widely adopted across Europe and operates under strict environmental standards defined by the Industrial Emissions Directive (European Parliament & Council, 2010).

The conceptual plant design assumed in this study includes:

- **Annual treatment capacity:** ~120,000–130,000 tonnes of residual waste
- **Technology:** Moving-grate thermal treatment
- **Electricity generation:** Steam turbine generator system
- **Emission control:** BAT-compliant flue gas treatment systems
- **Operational hours:** ~8,000 hours per year

The proposed facility also incorporates:

- bottom ash processing infrastructure,
- ferrous and non-ferrous metal recovery systems,
- and potential secondary aggregate valorization pathways.

These components strengthen the circular economy dimension of the project by reducing landfill disposal requirements and enabling secondary material recovery (Šyc et al., 2020; Bandarra et al., 2021).

The plant is assumed to operate primarily as an electricity-generating facility, although future integration of Combined Heat and Power (CHP) could increase overall energy efficiency if industrial heat demand becomes available in the host region (European Commission, 2019).

The integration of CHP systems is particularly important because it significantly improves overall energy recovery efficiency compared to electricity-only operation. In addition to strengthening project revenues, CHP operation may contribute to:

- regional energy resilience,
- fossil fuel displacement,
- and decarbonization objectives.

Overall, the proposed facility is positioned not as a replacement for recycling systems, but as a complementary residual waste treatment solution aligned with EU landfill diversion and circular economy objectives.

4.1.1 PESTEL Analysis of Waste-to-Energy Development in Greece

The development of Waste-to-Energy (WtE) infrastructure is influenced by a complex external environment shaped by political, economic, social, technological, environmental, and legal factors. A PESTEL analysis provides a structured framework for evaluating these macro-environmental influences and their implications for the proposed project (Johnson et al., 2020).

- **Political Factors**

Waste management policy in Greece is heavily shaped by EU legislation and funding mechanisms, particularly in the areas of waste management and climate change. The Waste Framework Directive and the Circular Economy Action Plan impose binding targets on landfill reduction and recycling rates (European Commission, 2020).

In addition, the Just Transition Mechanism provides financial support for regions affected by the phase-out of lignite, including Megalopolis. This creates a favorable political environment for the development of alternative energy infrastructure such as WtE plants.

However, political risks remain, including potential changes in regulatory priorities and public opposition to large-scale infrastructure projects.

- **Economic Factors**

The economic feasibility of WtE projects depends on several key variables, including gate fees, electricity prices, and capital costs. In Greece, gate fees for waste treatment are currently around €80 per tonne, which is relatively competitive compared to European averages.

Electricity market volatility represents an important economic risk. However, the addition of district heating and potential carbon pricing mechanisms can significantly improve financial performance.

Furthermore, access to EU funding mechanisms can reduce capital expenditure requirements and improve investment attractiveness.

- **Social Factors**

Public perception plays a critical role in the development of WtE facilities. Concerns related to air pollution, health risks, and environmental impact often lead to resistance from local communities.

Studies indicate that transparency, stakeholder engagement, and real-time emissions monitoring can significantly improve public acceptance (EEA, 2022).

European experience demonstrates that social acceptance improves significantly when WtE facilities are integrated within transparent environmental monitoring frameworks and clearly positioned as residual waste treatment infrastructure rather than as substitutes for recycling systems.

In the context of Megalopolis, the transition from lignite-based energy production to alternative infrastructure may enhance social acceptance if the project is framed as part of regional economic redevelopment.

- **Technological Factors**

WtE technologies are well-established and widely deployed across Europe. Advances in emission control, combustion efficiency, and digital monitoring systems have significantly improved environmental performance (European Commission, 2019).

Future technological developments, including carbon capture and storage (CCS), may further enhance the sustainability of WtE systems.

The potential integration of Combined Heat and Power (CHP) systems represents an important technological opportunity for increasing efficiency and revenue generation.

- **Environmental Factors**

Environmental considerations are central to WtE development. The primary environmental benefit of WtE lies in the reduction of landfill methane emissions and the displacement of fossil-based energy (IPCC, 2021).

However, WtE plants also produce CO_2 emissions from fossil-derived waste components. Therefore, environmental performance must be evaluated within a lifecycle framework.

Strict compliance with EU emission standards ensures that environmental impacts are controlled and monitored.

- **Legal Factors**

The legal framework governing WtE projects in Greece is primarily derived from EU legislation, including the Industrial Emissions Directive and the Waste Framework Directive.

Permitting processes can be complex and time-consuming, representing a potential barrier to project implementation.

Future regulatory developments, particularly related to carbon pricing and waste classification, may influence project viability.

PESTEL Summary

The analysis indicates that the external environment for WtE development in Greece is generally favorable, particularly due to strong policy support and infrastructure funding opportunities. However, social acceptance and regulatory complexity remain critical challenges that must be addressed through effective governance and communication strategies.

4.1.2 SWOT Analysis

In addition to the macro-environmental assessment provided by the PESTEL framework, a SWOT analysis is applied to evaluate the internal strengths and weaknesses of the proposed Waste-to-Energy (WtE) facility, as well as the external opportunities and threats influencing its development (Johnson et al., 2020).

- **Strengths**

- Stable and predictable feedstock (~121,742 t/year)
- Dual revenue streams (gate fees + energy)
- Alignment with EU circular economy and landfill reduction policies
- Proven and mature technology with high reliability
- Strategic location (Megalopolis) with existing grid infrastructure
- Potential for CHP integration (high efficiency)
- Additional circular economy value through ash valorization and metal recovery

- **Weaknesses**

- High capital expenditure (~€110M)
- Dependence on gate fee stability

- Moderate electrical efficiency (without CHP)
- Lack of existing district heating infrastructure in Greece
- Limited experience with WtE projects at national level

- **Opportunities**

- Integration of district heating (CHP)
- Access to EU funding (Just Transition Mechanism)
- Increasing landfill restrictions
- Potential inclusion in circular economy financing tools
- Future carbon pricing incentives
- Industrial symbiosis opportunities
- Secondary material recovery and aggregate reuse markets

- **Threats**

- Public opposition (NIMBY effect)
- Regulatory delays and permitting complexity
- Potential inclusion in EU ETS (increased costs)
- Waste reduction policies reducing feedstock long-term
- Electricity price volatility

- **SWOT Conclusion**

The SWOT analysis indicates that while the project faces financial and social challenges, the integration of CHP and strong policy alignment significantly strengthen its long-term viability.

4.2 Feedstock Structure: MSW, RDF/SRF and Residual Waste Streams

The feedstock for the proposed WtE plant consists primarily of residual municipal waste derived from Mechanical-Biological Treatment (MBT/MEA) facilities, supplemented by refuse-derived fuel (RDF) and solid recovered fuel (SRF) fractions.

Existing treatment facilities in the Peloponnese region generate residual fractions following mechanical sorting and biological stabilization. These residual fractions typically represent 39–45% of incoming waste, depending on facility configuration and waste composition.

Based on reported facility capacities and residual rates, the following feedstock contributions were estimated:

Region / Facility	**Annual Capacity (t)**	**Residual Fraction**	**Residual Waste (t/year)**
Paliochouni (Arcadia)	105,000	45%	47,250
Kalliroi (Messinia)	65,000	45%	29,250
Skala (Laconia)	30,000	45%	13,500
Triantafyllia (Ilia)	70,000	39%	27,300
Planned Achaia facility	55,000	39%	21,450

Additional residual waste was estimated for Western Greece and the Ionian Islands, based on population-adjusted projections and expected landfill diversion targets.

After accounting for landfill reduction targets and waste hierarchy compliance, the effective feedstock for the proposed WtE facility was estimated at approximately 121,742 tonnes per year. This value corresponds to the annual feedstock estimate developed previously and constitutes the reference quantity used throughout the subsequent technical and financial analyses.

This feedstock structure aligns with EU practice, where WtE plants typically operate on post-sorting residual waste rather than untreated municipal waste streams (Brunner & Rechberger, 2015).

The analysis therefore suggests that sufficient residual waste volumes exist to support the long-term operation of a medium-scale Waste-to-Energy facility in Southern Greece under realistic landfill diversion and recycling scenarios.

At the same time, the findings indicate that long-term feedstock stability remains strongly dependent on:

- interregional cooperation,
- continued operation of MBT/MEA infrastructure,
- and the balance between recycling performance and residual waste generation.

These findings directly address Research Question 1 regarding long-term feedstock sufficiency.

4.3 Energy Recovery Potential

Energy recovery potential was calculated based on the Lower Heating Value (LHV) of residual municipal waste.

Residual waste calorific value varies depending on moisture content, plastics fraction, and pre-treatment processes. European studies indicate that LHV for residual municipal waste typically ranges between 10 and 15 MJ/kg (Scarlat et al., 2019).

To account for uncertainty, three scenarios were modeled:

Scenario	LHV (MJ/kg)
Conservative	10
Base Case	12
Optimistic	15

Under the base-case scenario, annual thermal energy input is calculated as:

$$E_{therm} = Q \times LHV$$

Where:

Q = 121,742 tonnes/year

This yields approximately:

$$E_{therm} \approx 405{,}800 \text{ MWh/year (thermal)}$$

Assuming a net electrical conversion efficiency of 22%, typical for electricity-only WtE plants, the estimated electricity generation equals:

$$E_{electric} \approx 89{,}278 \text{ MWh/year}$$

This corresponds to approximately 89 GWh annually, sufficient to supply electricity to roughly 20,000–25,000 households, depending on average consumption levels.

The integration of Combined Heat and Power (CHP) systems represents a significant enhancement in the performance of Waste-to-Energy facilities. CHP allows simultaneous production of electricity and useful heat, increasing total energy efficiency from approximately 20–25% to over 70% (European Commission, 2019).

Energy Balance

From Section 4.3:

- Thermal input: ~405,800 MWh/year
- Electricity output: ~89,278 MWh/year

Remaining heat:

$$\approx 316{,}522 \text{ MWh/year}$$

Assuming 40% utilization:

$$Useful\ Heat \approx 126{,}600 \text{ MWh/year}$$

The results indicate that CHP integration substantially improves total energy efficiency compared to electricity-only operation.

In addition to improving project revenues, CHP integration strengthens:

- overall system efficiency,
- fossil fuel displacement,
- regional energy resilience,
- and long-term decarbonization performance.

The analysis therefore suggests that CHP operation represents one of the most important determinants of the strategic and financial viability of the proposed WtE facility.

District Heating Potential

District heating systems distribute heat to:

- residential areas

- public buildings
- industrial users

In Northern Europe, WtE plants supply up to 90% of district heating demand in some cities (Scarlat et al., 2019).

4.4 Cost–Benefit Analysis

4.4.1 Capital Expenditure (CAPEX)

Capital expenditure for modern WtE plants varies depending on plant capacity, environmental controls, and site conditions. European benchmarks suggest typical costs between €500 and €900 per annual tonne of installed capacity (OECD, 2018).

For the proposed facility, CAPEX was conservatively estimated at:

$$CAPEX \approx €110\, million$$

This estimate includes:

- plant construction
- energy generation systems
- emission control technology
- grid connection
- engineering and permitting costs

4.4.2 Operating Expenditure (OPEX)

Operating costs were estimated based on European WtE operational benchmarks.

Typical OPEX ranges from €80 to €120 per tonne, depending on plant size and labor costs (OECD, 2018).

This study adopts a base assumption of:

$$OPEX = 90€/t$$

For the projected feedstock volume:

$$OPEX \approx €10.96M/year$$

4.4.3 Revenue Streams

The facility generates two main revenue streams.

- **Gate Fee Revenue**

Gate fees represent payments by municipalities for waste treatment.

The current gate fee in Peloponnese treatment facilities is approximately €80 per tonne.

Annual gate fee revenue therefore equals:

$$R_{gate} = 121{,}742 \times 80$$

$$R_{gate} \approx €9.74M/year$$

- **Electricity Revenue**

Electricity revenues depend on wholesale market prices.

European WtE electricity revenues typically range between €70 and €150 per MWh, depending on energy market conditions.

Assuming a base-case price of €105/MWh, annual electricity revenue is estimated as:

$$R_{electric} = 89{,}278 \times 105$$

$$R_{electric} \approx €9.37M/year$$

- **Revenue from Heat Sales**

Assuming:

- Heat price: €35/MWh (conservative)

$$126{,}600 \times 35 = €4.43M/year$$

- **Revenue from Ash Valorization and Metal Recovery**

In addition to gate fee income and energy generation, the financial model also considers revenues associated with bottom ash recovery and material valorization.

Modern Waste-to-Energy facilities increasingly incorporate:

- ferrous metal recovery,

- non-ferrous metal recovery,
- and secondary aggregate production from processed bottom ash.

Based on European operational benchmarks, bottom ash generation was assumed at approximately 20–25% of incoming waste mass (Šyc et al., 2020).

Assuming conservative recovery and market utilization conditions, additional annual revenues of approximately:

$€0.5 - 0.6M/year$

were estimated.

Although smaller than electricity or gate fee revenues, ash valorization contributes positively to:

- project resilience,
- circular economy integration,
- and landfill diversion performance.

- **Total Revenue**

Total annual revenue therefore equals:

$$R_{total} \approx €24.1M/year$$

In the CHP scenario, total annual revenue includes gate fee income, electricity sales, commercially usable heat sales and . Therefore, the annual net operating cash flow is estimated after deducting annual OPEX from total CHP-based revenue.

4.4.4 Investment Performance Indicators

Using a 25-year project lifetime and a 6% discount rate, the discounted cash-flow model yields:

Indicator	Value
Annual net operating cash flow	~€13.1M
Net Present Value (NPV)	~€52-55M
Simple payback period	~8-9 years
Discounted payback period	~11-13 years

Indicator	Value
Internal Rate of Return (IRR)	~10-11%

These results indicate that, under the CHP scenario, the project becomes financially viable, mainly due to:

- the additional heat revenue stream,
- ash valorization revenues,
- and the stability of gate fee income.

The results indicate that the financial viability of the project depends strongly on:

- CHP integration,
- stable gate fee structures,
- and long-term feedstock availability.

Among the examined variables, CHP utilization appears to have the strongest positive effect on:

- project profitability,
- NPV,
- and long-term investment resilience.

The analysis therefore suggests that electricity-only operation would significantly weaken financial performance compared to integrated CHP operation.

4.5 Site Selection and Spatial Evaluation

The optimal location of the proposed Waste-to-Energy (WtE) facility was evaluated using a **Multi-Criteria Decision Analysis (MCDA)** framework. The objective of the analysis was to identify the most suitable location by considering not only technical and logistical parameters, but also the strategic, economic and governance factors identified throughout this study as critical determinants of project viability.

Consistent with the previous findings, the MCDA framework was designed to evaluate the candidate locations against the factors that most strongly influence the long-term success of a regional Waste-to-Energy facility, namely feedstock security, infrastructure availability, CHP integration potential, governance capacity and environmental suitability.

Three candidate regions were evaluated:

- Arcadia (Megalopolis)
- Ilia
- Achaia

The criteria applied include:

Criterion	**Weight %**
Feedstock availability	20
Transportation and logistics	15
Existing energy and grid infrastructure	15
CHP and industrial heat utilisation potential	15
Governance and Just Transition alignment	15
Environmental suitability	10
Social acceptance potential	10

Each criterion was evaluated using a five-point scoring scale, where 1 represents very weak performance and 5 represents very strong performance. Weighted scores were calculated by multiplying each criterion score by its assigned weighting factor. The final site ranking was then derived from the cumulative weighted score for each location.

Criterion	**Weight**	**Megalopolis**	**Ilia**	**Achaia**
Feedstock availability	20%	**5**	4	4
Transportation & logistics	15%	**5**	3	4
Existing energy & grid infrastructure	15%	**5**	3	3
CHP utilisation potential	15%	**5**	3	3
Governance & Just Transition alignment	15%	**5**	3	3

Criterion	Weight	Megalopolis	Ilia	Achaia
Environmental suitability	10%	**4**	4	3
Social acceptance potential	10%	**4**	3	4

The weighted scoring results were:

Location	Final Score
Megalopolis	4.80
Ilia	3.50
Achaia	3.40

The MCDA results indicate that **Megalopolis** represents the most suitable location for the proposed Waste-to-Energy facility. Its superior score is primarily attributed to its proximity to the largest residual waste generation centres, existing electricity transmission infrastructure, high potential for Combined Heat and Power (CHP) utilisation, and strong alignment with Greece's Just Transition Strategy following the phase-out of lignite-based electricity generation.

In addition, Megalopolis benefits from its central geographical position within the proposed catchment area, allowing shorter transportation distances from the existing Mechanical-Biological Treatment (MBT) facilities while improving long-term feedstock security. These characteristics are consistent with the financial and operational assumptions developed in Chapter 3 and reinforce the positive economic results presented in Chapter 4.

Although **Achaia** and **Ilia** also demonstrate several favourable characteristics, lower scores in infrastructure readiness, governance coordination and CHP development opportunities reduce their overall suitability compared with Megalopolis.

It should be noted that the MCDA framework is intended to support strategic decision-making rather than replace detailed engineering or environmental site investigations. Consequently, the results should be interpreted as a comparative planning tool based on the assumptions adopted in this study. Future project development should include detailed geotechnical investigations, environmental impact assessment, stakeholder consultation and engineering design before a final site selection is confirmed.

4.6 Environmental Benefits and CO_2 Emissions Avoidance

The environmental performance of the proposed facility was evaluated by comparing emissions associated with landfill disposal and energy recovery.

Residual waste landfilling generates methane emissions due to anaerobic decomposition of organic waste. Methane has a significantly higher global warming potential than carbon dioxide (IPCC, 2021).

Based on European lifecycle assessments, WtE facilities can reduce greenhouse gas emissions by 0.3–0.6 tonnes of CO_2 equivalent per tonne of waste treated (Scarlat et al., 2019).

Applying this range to the projected feedstock:

$CO_{2,avoided} = 121{,}742 \times (0.3–0.6)$

This yields an estimated annual reduction of:

$$36{,}500–73{,}000 \ tCO_2e/year$$

These reductions arise from:

- avoided landfill methane emissions
- displacement of fossil electricity generation
- Reduced fossil heating demand
- Lower CO_2 emissions from heating sector
- Higher overall system efficiency

Additional environmental benefits may also arise from:

- bottom ash valorization,
- secondary aggregate utilization,
- and metal recovery processes.

These practices reduce demand for virgin raw materials and further strengthen the circular economy performance of the proposed facility (Bandarra et al., 2021).

The analysis therefore indicates that the proposed facility could generate measurable environmental benefits compared to continued landfill dependency, particularly under CHP-integrated operation.

Summary of Base-Case Technical, Financial and Environmental Results

Parameter	**Base-Case Result**
Annual Feedstock	121,742 t/year
Lower Heating Value	12 MJ/kg
Electricity Generation	89 GWh/year
Recoverable Heat (CHP)	126,600 MWh/year
Gate Fee	€80/t
Heat Revenue	€4.43 million/year
Ash Valorization Revenue	€0.5–0.6 million/year
Total Annual Revenue	≈ €24.1 million
Annual OPEX	≈ €10.96 million
Net Operating Cash Flow	≈ €13.1 million
CAPEX	€110 million
Net Present Value (NPV)	≈ €52–55 million
Internal Rate of Return (IRR)	≈10–11%
Simple Payback	≈8–9 years
Discounted Payback	≈11–13 years
Estimated CO_2 Reduction	36,500–73,000 tCO_2e/year

This table summarises the principal technical, financial and environmental outputs of the base-case scenario developed in Chapter 3 and evaluated throughout Chapter 4. These results constitute the reference case used for the comparative discussion presented in Chapter 5 and for the conclusions and policy recommendations developed in Chapter 6.

4.7 Strategic Viability and Policy Alignment

The analysis demonstrates that the proposed WtE facility aligns with key European and national policy objectives, including landfill reduction targets and circular economy implementation.

When positioned as a residual waste treatment facility rather than a replacement for recycling, WtE can function as a complementary component within the waste hierarchy (European Commission, 2020).

Furthermore, locating the facility in Megalopolis supports regional economic transition policies by providing new industrial activity in areas affected by lignite phase-out.

Overall, the findings of Chapter 4 indicate that the proposed Waste-to-Energy facility could become:

- technically feasible,
- financially viable,
- environmentally beneficial,
- and strategically aligned with EU waste policy objectives,

provided that:

- CHP integration,
- stable governance structures,
- long-term feedstock agreements,
- and strong circular economy integration
  are successfully implemented.

The analysis also demonstrates that the long-term success of the project depends not only on technical and financial performance, but also on:

- public acceptance,
- institutional coordination,
- and integration within broader regional waste management planning.

5.Comparative Analysis and Lessons from the European Union

5.1 Waste-to-Energy Development in Germany, Italy, and Sweden

The findings presented in Chapter 4 demonstrated that the long-term viability of the proposed Greek Waste-to-Energy (WtE) facility depends strongly on:

- stable governance structures,
- CHP integration,
- feedstock security,
- and regional coordination.

In order to interpret these findings within a broader policy and operational context, this chapter examines the experience of mature European Waste-to-Energy systems, particularly in Germany, Sweden, and Italy.

Waste-to-Energy deployment across Europe varies significantly depending on:

- national waste management strategies,
- landfill policies,
- governance structures,
- public acceptance levels.

Germany, Sweden, and Italy represent three distinct yet mature WtE systems that provide useful comparative benchmarks for evaluating the potential development of WtE infrastructure in Greece.

Germany operates one of the most advanced waste management systems in Europe. Following the introduction of strict landfill bans for untreated municipal waste in 2005, the country invested heavily in recycling and thermal treatment infrastructure (Brunner & Rechberger, 2015).

Today, Germany combines:

- high recycling rates,
- strong landfill restrictions,
- extensive WtE capacity, ensuring that residual waste fractions are treated through energy recovery rather than landfilled (EEA, 2022) .

The German experience is particularly relevant for the Greek case as identified previously, feedstock stability and long-term contractual certainty as critical determinants of project viability. This finding is consistent with the estimated annual feedstock of approximately **121,742 tonnes** identified for the proposed Greek facility.

Germany demonstrates that strict landfill regulation combined with long-term waste supply agreements can create the institutional stability required for successful WtE deployment.

Sweden presents a different model in which WtE plants are strongly integrated into district heating networks. In this system, thermal energy generated during waste incineration is used for urban heating, significantly increasing overall energy efficiency.

Swedish WtE plants therefore often operate in Combined Heat and Power (CHP) mode, achieving higher energy recovery rates compared to electricity-only plants (Scarlat et al., 2019).

The Swedish model directly reinforces the importance of CHP integration.

As demonstrated in the financial analysis, CHP operation significantly improves both:

- overall energy efficiency,
- and long-term project profitability.

The Swedish experience therefore supports the argument that CHP integration should be considered a strategic prerequisite rather than an optional enhancement for the proposed Greek facility. As demonstrated previously, CHP integration increases annual revenues through approximately **126,600 MWh/year** of recoverable heat, substantially improving the project's financial performance.

Italy represents a more heterogeneous system characterized by regional variation. Northern regions such as Lombardy have developed extensive WtE capacity, while southern regions continue to rely more heavily on landfill disposal.

This disparity highlights the importance of governance consistency and regional planning in developing effective waste management infrastructure (EEA, 2022). Italy's regional disparities also reflect the importance of governance coordination and regional planning.

The differences between Northern and Southern Italy illustrate how inconsistent institutional capacity may lead to uneven infrastructure development and long-term operational inefficiencies.

Overall, the comparison between Germany, Sweden, and Italy suggests that technological capability alone is insufficient without:

- stable governance,
- long-term planning,
- and integration within broader waste and energy systems.

5.2 Governance and Financing Mechanisms

Governance stability emerges as a critical condition for the successful implementation of the proposed WtE facility.

European experience shows that effective WtE systems depend on stable regulatory frameworks, long-term waste supply arrangements, and clear institutional coordination. Governance structures vary across countries but commonly involve close collaboration between public authorities and private operators. Many facilities are developed through Public–Private Partnerships (PPP), which distribute financial risk and operational responsibility between municipalities and private investors (OECD, 2018).

Municipalities typically secure waste supply through long-term contracts that ensure plants operate at sufficient capacity to remain economically viable. These agreements usually include minimum waste volume commitments, gate fee arrangements, and long-term operational guarantees, contributing to feedstock security and financial predictability.

Financing structures often combine municipal guarantees, long-term energy offtake agreements, infrastructure loans, and private-sector participation. Stable regulatory environments are essential for attracting investment, as they provide certainty regarding waste volumes, energy pricing, and environmental compliance requirements.

In the Greek context, these insights indicate that successful implementation would depend on interregional coordination, robust contractual frameworks, and transparent governance structures. Without such conditions, investment risk would remain significantly elevated.

5.3 Technological Innovation and Performance Indicators

Modern WtE plants operate using highly advanced environmental and energy recovery technologies. Continuous improvements in combustion efficiency, emission control, and digital monitoring systems have significantly enhanced environmental performance over the past decades.

Key technological components of modern WtE facilities include:

- moving-grate combustion systems
- advanced flue gas treatment systems
- automated combustion control
- continuous emissions monitoring systems (CEMS)

In addition, modern European facilities increasingly integrate bottom ash valorization, ferrous and non-ferrous metal recovery, and secondary aggregate production. These circular economy practices improve both environmental performance and financial resilience, while reducing landfill disposal requirements (Šyc et al., 2020; Bandarra et al., 2021).

According to the European Commission's Best Available Techniques (BAT) Reference Document for Waste Incineration, modern plants achieve high operational reliability while maintaining strict emission limits (European Commission, 2019).

Typical performance indicators for WtE facilities include:

Indicator	**Typical EU Range**
Electrical efficiency	20–27%
Overall efficiency (CHP)	up to 80%
Availability	>8,000 hours/year
Waste treatment capacity	100,000–600,000 t/year

These benchmarks provide useful reference points when evaluating the design assumptions of the proposed Greek facility.

5.4 Public–Private Partnerships (PPP)

Public–Private Partnerships have become a common institutional framework for WtE infrastructure development in Europe. Under PPP arrangements, municipalities often retain ownership of waste supply contracts while private partners provide engineering expertise, operational management, and financing.

The advantages of PPP models include:

- improved access to private capital
- risk sharing between public and private sectors
- enhanced operational efficiency
- reduced financial burden on municipalities

However, successful PPP implementation requires clearly defined contractual frameworks and transparent risk allocation mechanisms. The European experience suggests that PPP structures are particularly effective in large infrastructure projects where long operational lifetimes and stable revenue streams justify private investment.

5.5 Common Success Factors and Policy Lessons

The comparative analysis of European Waste-to-Energy systems provides important interpretative insight into the findings presented earlier in this study.

The Greek case demonstrated that CHP integration increased annual project revenues and contributed to a positive NPV of approximately **€52–55 million**, confirming the strategic importance of high-efficiency energy recovery.

The European experience therefore reinforces the conclusion that the long-term success of the proposed Greek facility depends less on technological capability and more on institutional stability, policy consistency, and integration within broader circular economy frameworks.

Several recurring success factors emerge consistently across mature European WtE systems.

First, strict landfill regulation plays a central role in encouraging alternative waste treatment solutions. Countries with high landfill taxes or landfill bans have developed stronger WtE capacity because landfill disposal becomes economically unattractive.

Second, stable waste supply contracts ensure that WtE plants operate at optimal capacity. Without guaranteed feedstock volumes, the financial viability of such capital-intensive facilities becomes uncertain.

Third, public transparency and environmental monitoring significantly influence public acceptance. Many European facilities provide real-time emissions data, transparent reporting systems, and local community engagement mechanisms.

Finally, integration with energy systems increases the efficiency and economic value of WtE plants. As demonstrated quantitatively in the analysis, the inclusion of CHP transformed the project from a marginal investment scenario into a financially robust infrastructure model with significantly improved NPV and IRR performance.

5.6 Adaptation Potential in Greece

The lessons derived from European WtE systems provide valuable insights for the potential development of similar infrastructure in Greece.

The proposed facility in Southern Greece demonstrates several structural similarities with successful European models:

- interregional waste catchment area
- integration within the waste hierarchy
- compliance with EU environmental regulations
- potential alignment with Just Transition policies

However, certain challenges remain specific to the Greek context. These include public acceptance concerns, regulatory complexity, and financial risk associated with large infrastructure investments.

Addressing these challenges requires careful policy design, transparent governance structures, and stable contractual arrangements between municipalities and plant operators. The findings indicate that the Greek case can become viable under conditions similar to those observed in mature European systems, particularly when CHP integration, stable governance, and long-term waste agreements are successfully implemented.

5.7 Comparative Policy Effectiveness and Structural Differences

Germany, Sweden, and Italy all demonstrate advanced WtE deployment, significant differences exist in the effectiveness of their policy frameworks and implementation strategies.

These differences highlight that the success of WtE systems depends less on technological capability and more on institutional design, governance consistency, and integration with broader energy systems.

Germany's model is often considered the most structurally robust due to strict landfill bans, strong regulatory enforcement, and long-term waste management planning. The prohibition of untreated waste disposal effectively eliminated landfill as a low-cost alternative, forcing municipalities to adopt recycling, material recovery, and energy recovery solutions (Brunner & Rechberger, 2015).

In contrast, Sweden's model emphasizes energy system integration. The success of Swedish WtE systems is strongly linked to district heating infrastructure, allowing facilities to operate at significantly higher overall efficiency and making combined heat and power generation a central component of system performance.

Italy presents a more fragmented model in which regional disparities significantly influence infrastructure development. The divergence between Northern and Southern Italy demonstrates how inconsistent governance capacity may lead to uneven infrastructure deployment, operational inefficiencies, and continued landfill dependence.

Taken together, these cases illustrate that governance quality and policy consistency are among the most important determinants of long-term WtE success.

5.8 Policy Critique: Limitations of the European Waste-to-Energy Model

Although European WtE systems provide important lessons for Greece, several criticisms and structural limitations must also be considered. In particular, concerns have been raised regarding the potential for WtE infrastructure to create technological lock-in effects, where long-term contractual obligations and high capital investments may discourage further improvements in waste prevention and recycling. Additionally, variations in waste composition, population density, and institutional capacity across Member States limit the direct transferability of best practices. These considerations highlight the importance of adapting European experiences to the specific socio-economic and regulatory context of Greece, ensuring that WtE development complements rather than undermines broader circular economy objectives.

5.8.1 Risk of Infrastructure Lock-In

However, empirical evidence suggests that this risk can be mitigated through the implementation of strict recycling targets, strong landfill regulation, and clearly defined residual waste streams.

For the proposed Greek facility, this finding highlights the importance of maintaining robust recycling policies and ensuring that the plant operates exclusively on non-recyclable waste fractions.

This interpretation reinforces the strategic positioning of the project within the waste hierarchy.

5.8.2 Competition with Recycling

Another important concern relates to the potential competition between WtE and recycling. High calorific value materials, particularly plastics, may be diverted to energy recovery rather than recycling if economic incentives are not properly aligned.

This issue highlights the importance of policy design. In systems where recycling targets are strictly enforced, WtE serves as a complementary technology. In contrast, weak regulatory frameworks may allow energy recovery to displace recycling efforts. The Greek case therefore requires careful policy coordination in order to ensure that WtE infrastructure complements rather than competes with recycling systems.

Recent studies emphasize that the relationship between recycling and WtE is not inherently competitive but depends on governance structures and policy priorities (Iacovidou et al., 2020).

5.8.3 Carbon Emissions and Climate Policy

While WtE reduces methane emissions from landfill, it also generates CO_2 emissions from fossil-derived waste fractions. This has led to increasing debate regarding the role of WtE within climate policy frameworks.

The potential inclusion of WtE in the European Union Emissions Trading System (EU ETS) represents a significant policy development that could impact the economic viability of such facilities (EEA, 2022). This issue is particularly relevant for the proposed Greek facility because future EU carbon pricing mechanisms could significantly influence long-term operational costs and investment performance.

If carbon pricing is applied to WtE emissions, operational costs may increase, particularly for facilities processing high-plastic-content waste streams. However, this could also incentivize:

- improved waste sorting

- increased recycling
- development of carbon capture technologies

5.8.4 Public Acceptance Challenges

Public opposition remains one of the most significant barriers to WtE development. Even in countries with strong environmental regulations, local communities often resist the construction of new incineration facilities due to perceived health and environmental risks.

This phenomenon, commonly referred to as the "Not In My Backyard" (NIMBY) effect, highlights the importance of stakeholder engagement and transparency (EEA, 2022).

European experience indicates that public acceptance improves when:

- emissions data is publicly available
- facilities operate under strict monitoring
- local communities receive economic benefits

5.9 Strategic Lessons for Greece

The comparative analysis and policy critique provide several important lessons for the Greek case.

5.9.1 Importance of Regulatory Stability

One of the key factors influencing WtE success in Europe is regulatory certainty. Long-term investment in infrastructure requires stable policy frameworks and clear waste management strategies.

For Greece, this implies the need for:

- clear landfill reduction targets
- stable gate fee structures
- long-term waste supply contracts

Without these elements, investment risk remains high.

5.9.2 Integration with Energy Systems (Critical Insight)

A major lesson from Sweden is the importance of integrating WtE within energy systems. The inclusion of district heating significantly improves both environmental and financial performance.

For the proposed facility in Megalopolis, the development of CHP and district heating infrastructure represents a key opportunity. As demonstrated in Chapter 4, the inclusion of heat recovery transforms the project from marginally viable to strongly profitable.

5.9.3 Governance and Regional Coordination

Italy's experience highlights the importance of regional coordination. Inconsistent governance structures can lead to uneven infrastructure development and inefficiencies.

Given that the proposed Greek facility serves multiple regions, effective coordination between:

- Peloponnese
- Western Greece
- Ionian Islands

is essential for project success.

5.9.4 Public Acceptance Strategy

European experience demonstrates that public acceptance is not automatic but must be actively managed.

For Greece, this requires:

- transparent environmental reporting
- early stakeholder engagement
- clear communication of benefits
- integration with regional development strategies

The Just Transition framework provides an opportunity to position WtE as part of broader economic transformation rather than as a standalone waste project.

5.9.5 Circular Economy Integration and Ash Valorization

An additional finding relates to the contribution of ash valorization and secondary material recovery to the overall circular economy performance of the proposed facility.

Modern European Waste-to-Energy plants increasingly integrate bottom ash processing, metal recovery, and secondary aggregate utilization within broader circular economy frameworks. These practices reduce landfill disposal requirements while simultaneously improving resource efficiency, project revenues, and environmental performance.

The incorporation of ash valorization within the Greek case therefore aligns the proposed facility more closely with mature European Waste-to-Energy models, particularly those emphasizing material recovery alongside energy generation (Šyc et al., 2020; Bandarra et al., 2021).

Although ash valorization represents a relatively smaller revenue stream compared to gate fees and CHP operation, it strengthens both financial diversification and circular economy integration.

5.10 Critical Positioning of the Greek Case

Based on the analysis, the proposed WtE facility in Megalopolis can be positioned as a late adopter of a mature European model rather than an experimental investment.

This positioning has important implications:

- technological risks are low
- financial models are well established
- policy frameworks are already defined at EU level

However, Greece must avoid replicating the weaknesses observed in other countries, particularly in relation to:

- governance fragmentation
- public opposition
- lack of system integration
- and insufficient integration with broader energy systems

Overall, the comparative European analysis suggests that the proposed Greek Waste-to-Energy facility should not be viewed as an experimental infrastructure project, but rather as a late-stage adaptation of a mature European model.

The findings, interpreted through the European experience examined in this chapter, indicate that the long-term success of the proposed facility depends primarily on governance stability, effective CHP integration, alignment with circular economy principles, secure feedstock agreements, and sustained public acceptance.

The European experience therefore supports the conclusion that Waste-to-Energy can function as a strategically valuable residual waste treatment solution for Greece, provided that it remains integrated within broader recycling and landfill reduction policies.

6.Conclusions and Strategic Recommendations

6.1 Summary of the Study and Key Findings

This dissertation examined the strategic, financial, and environmental feasibility of establishing a medium-scale Waste-to-Energy (WtE) facility serving the Region of Peloponnese together with Western Greece and the Ionian Islands (excluding Corfu). The study addressed the growing challenge of residual municipal solid waste management in Greece within the framework of European Union waste and climate policies.

The analysis combined policy review, quantitative modeling, financial evaluation, and spatial analysis in order to assess whether a WtE facility could represent a viable component of Greece's waste management system.

The results demonstrate that sufficient residual waste volumes exist to support a medium-scale facility. Based on data from existing Mechanical-Biological Treatment (MBT/MEA) plants and projected landfill diversion targets, the annual feedstock available for energy recovery was estimated at 121,742 tonnes per year.

These results also demonstrate whether there will be enough residual waste available over the long term to support a medium-scale Waste-to-Energy facility in Southern Greece. Energy recovery modeling showed that, under a base-case Lower Heating Value (LHV) of 12 MJ/kg and an electrical efficiency of approximately 22%, the facility could produce around 89 GWh of electricity annually. This level of generation corresponds to the electricity consumption of approximately 20,000–25,000 households.

The financial evaluation indicated that the economic viability of the project depends primarily on gate fee levels, CHP integration, and long-term feedstock stability. Under the base-case assumption of €80 per tonne gate fee, a 25-year project lifetime, and a 6% discount rate, the electricity-only scenario produces weaker financial results, whereas the CHP-integrated scenario generates positive Net Present Value (NPV), stronger Internal Rate of Return (IRR), and improved investment resilience. The financial analysis also demonstrated that CHP integration represents one of the most important determinants of long-term project viability, significantly improving both Net Present Value (NPV) and Internal Rate of Return (IRR). Moderate increases in gate fee levels significantly improve financial performance. A break-even gate fee of approximately €84 per tonne was identified, while values in the range of €90–95 per tonne generate clearly positive financial outcomes.

Environmental assessment suggests that the proposed facility would deliver measurable climate benefits. Based on lifecycle emission comparisons between landfill disposal and energy recovery, the plant could reduce greenhouse gas emissions by approximately 36,000 to 73,000 tonnes of CO_2 equivalent annually (Scarlat et al., 2019; IPCC, 2021). These reductions result primarily from avoided landfill methane emissions and displacement of fossil-based electricity generation. These reductions result primarily from avoided landfill methane emissions, displacement of fossil-based electricity generation, and improved energy recovery efficiency under CHP operation. These findings help clarify the environmental implications of Waste-to-Energy compared to continued reliance on landfilling. The analysis also demonstrated that ash valorization, secondary aggregate utilization, and metal recovery can provide additional environmental and financial benefits while strengthening the circular economy performance of the proposed facility.

Finally, the spatial evaluation conducted using Multi-Criteria Decision Analysis identified Megalopolis as the most suitable location for the proposed facility. The area's existing energy infrastructure, central geographical position, and alignment with Greece's Just Transition strategy for former lignite regions make it particularly well suited for the development of new energy infrastructure.

6.2 Strategic Implications

The findings of this dissertation highlight the strategic role that Waste-to-Energy infrastructure can play in supporting Greece's transition toward a more sustainable waste management system.

One of the main strategic advantages of the proposed facility is its potential contribution to landfill diversion targets. The Waste Framework Directive establishes a clear hierarchy of waste treatment options, with landfill representing the least desirable option (European Parliament & Council, 2008). By diverting residual waste streams from landfill, WtE infrastructure can support compliance with these targets while simultaneously reducing methane emissions.

Second, the project supports broader energy system diversification. Although WtE is not classified as a renewable energy source in the strict sense, the energy recovered from waste can contribute to energy security by providing stable and predictable electricity generation (European Commission, 2020). The inclusion of Combined Heat and Power (CHP) systems further strengthens the strategic role of the proposed facility by improving overall energy efficiency, enhancing regional energy resilience, and contributing to decarbonization performance.

Third, locating the facility in Megalopolis aligns with national economic transition policies. The region has historically depended on lignite-based electricity generation, and the ongoing phase-out of lignite has created a need for alternative economic activities and energy infrastructure. Developing WtE capacity in this region may therefore contribute to regional economic restructuring while making use of existing grid infrastructure.

The analysis also demonstrated that long-term project success depends heavily on governance stability, interregional coordination, and integration within broader circular economy frameworks. In particular, the incorporation of ash valorization, secondary material recovery, and metal recycling strengthens the project's alignment with circular economy principles by reducing landfill disposal requirements and improving resource recovery performance.

Importantly, the results also confirm that WtE should not be viewed as a substitute for recycling. Instead, it should be positioned as a complementary technology addressing the residual fraction of waste that cannot be recycled economically or technically (Brunner & Rechberger, 2015).

6.3 Financial Implications

The financial analysis conducted in Chapter 4 demonstrates that the economic feasibility of the project is highly sensitive to gate fee structures, CHP integration, and energy market conditions.

Gate fees represent the primary revenue source for WtE facilities, particularly in countries where electricity prices remain volatile. In the case of the proposed facility, gate fee revenues account for approximately half of total annual income. This finding is consistent with European experience, where stable waste supply contracts, predictable gate fee structures, and long-term municipal agreements are essential for ensuring the financial sustainability of WtE investments (OECD, 2018).

Electricity sales represent the second major revenue stream. Under the base-case electricity price assumption of €105/MWh, annual electricity revenues were estimated at approximately €9.37M/year. The analysis further demonstrated that CHP integration and ash valorization improve financial diversification by reducing dependence on electricity market volatility alone.

Although ash valorization represents a relatively smaller revenue stream compared to gate fees, electricity sales, and CHP operation, it contributes positively to project resilience, circular economy integration, and long-term operational sustainability.

The sensitivity analysis revealed that moderate increases in gate fee levels, CHP heat utilization, or electricity prices significantly improve project viability. This indicates that contractual design, regulatory stability, and energy system integration represent critical determinants of long-term financial performance.

6.4 Environmental Implications

The environmental analysis conducted in this study demonstrates that Waste-to-Energy facilities can provide measurable environmental benefits when compared with landfill disposal.

Landfills generate methane emissions during the anaerobic decomposition of organic waste. Methane is a potent greenhouse gas with a global warming potential significantly higher than carbon dioxide (IPCC, 2021). Diverting biodegradable waste from landfill therefore reduces methane emissions and contributes to climate mitigation.

In addition, electricity produced by WtE plants can replace electricity generated from fossil fuels, creating a substitution effect that further reduces overall greenhouse gas emissions.

Additional environmental benefits may arise from bottom ash valorization, secondary aggregate utilization, and metal recovery processes. These practices support circular economy objectives by reducing demand for virgin raw materials, improving material recovery, and minimizing landfill disposal requirements.

However, WtE facilities also generate carbon dioxide emissions from the combustion of fossil-derived waste fractions such as plastics. Consequently, environmental evaluation must consider the full lifecycle impact of different waste management pathways rather than focusing solely on direct plant emissions (Scarlat et al., 2019).

When evaluated within this broader system context, WtE generally performs better than landfill disposal for residual waste streams.

6.5 Policy Recommendations

Based on the findings of this study, several policy recommendations can be proposed to support the development of sustainable residual waste treatment infrastructure in Greece.

First, policymakers should establish stable long-term waste supply agreements between municipalities and facility operators. These agreements are necessary to guarantee sufficient feedstock volumes, reduce investment risk, and improve long-term financial predictability.

Second, regulatory frameworks should ensure transparency, environmental monitoring, and independent oversight. Public access to emissions data and continuous environmental reporting can improve public trust, stakeholder engagement, and social acceptance.

Third, financial mechanisms supporting infrastructure investment should be explored. European funding instruments associated with the Just Transition Mechanism could help reduce the financial burden associated with large capital investments.

In addition, policymakers should ensure strong interregional governance coordination mechanisms between participating municipalities and regional authorities. European experience demonstrates that long-term Waste-to-Energy success depends heavily on institutional stability, transparent governance structures, and stable waste supply agreements.

Policy frameworks should also encourage the development of Combined Heat and Power (CHP) integration opportunities, particularly in industrial applications, district heating systems, and greenhouse agriculture, where recoverable heat can improve overall system efficiency.

Finally, waste management policies should maintain strong support for recycling, waste prevention, and material recovery. WtE should be integrated within the waste hierarchy as a residual treatment option rather than replacing higher-priority waste management strategies.

6.6 Limitations of the Study

Several limitations should be acknowledged.

The analysis relies primarily on secondary data sources and modeled assumptions regarding waste volumes, calorific values, gate fee structures, and energy prices. While these assumptions are based on available literature and policy documents, actual operational conditions may differ.

Furthermore, the study does not include a full Life Cycle Assessment (LCA), which would provide a more comprehensive evaluation of environmental impacts across the entire waste management system.

In addition, the ash valorization scenario was evaluated using European benchmark assumptions rather than site-specific market analysis. Actual revenues from secondary aggregate utilization and metal recovery may therefore vary depending on local market conditions and regulatory acceptance.

Finally, social acceptance factors were not evaluated through empirical surveys. Public perception and stakeholder attitudes may significantly influence the feasibility of infrastructure development.

6.7 Future Research Directions

Future research could expand the present analysis in several directions.

First, detailed Life Cycle Assessment (LCA) studies could provide more precise estimates of environmental impacts across the full waste management chain.

Second, spatial analysis using Geographic Information Systems (GIS) could improve the evaluation of transport logistics, infrastructure optimization, and site selection.

Third, empirical research on public acceptance of Waste-to-Energy facilities in Greece could provide valuable insights for policymakers and project developers.

Future research could also examine site-specific ash valorization markets, secondary aggregate certification pathways, and the potential integration of carbon capture technologies within Greek Waste-to-Energy infrastructure.

Finally, future work could further investigate the long-term integration of Combined Heat and Power systems, particularly in relation to industrial heat demand, district heating infrastructure, and regional decarbonization strategies.

6.8 Final Conclusion

The results of this dissertation suggest that the development of a medium-scale Waste-to-Energy facility in Southern Greece is technically feasible, environmentally beneficial relative to landfill disposal, and financially viable under realistic market conditions.

When integrated within a comprehensive waste management strategy that prioritizes recycling, waste reduction, and circular economy principles, WtE infrastructure can contribute to achieving European landfill diversion targets while supporting regional economic transition.

Overall, the findings of this dissertation, interpreted through comparative European experience, suggest that the proposed Waste-to-Energy facility could represent a strategically viable residual waste treatment solution for Southern Greece.

The analysis demonstrated that sufficient residual feedstock appears to exist, CHP integration substantially improves financial viability, and circular economy practices such as ash valorization strengthen both environmental and economic performance.

At the same time, the study also demonstrated that long-term success depends not only on technological feasibility, but also on governance stability, public acceptance, stable waste supply agreements, and integration within broader recycling and landfill diversion policies.

Consequently, Waste-to-Energy should be viewed not as a replacement for recycling, but as a complementary infrastructure solution for the treatment of residual waste streams within Greece's transition toward a more circular and sustainable waste management system.

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