CHALMERS
UNIVERSITY OF TECHNOLOGY

Waste Management's Carbon Challenge: Energy Recovery vs. Transportation

Assessing the Environmental Impact of Waste-to-Energy Transportation

Degree project report in Supply Chain Management

Diego Alejandro Rivera Contreras
Elisabetta Gemelli

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

DEGREE PROJECT REPORT 2024

Diego Alejandro Rivera Contreras
Elisabetta Gemelli

Department of Technology Management and Economics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024

Supervisor: Ceren Altuntaş Vural, Chalmers, Technology Management and Economics
Examiner: Ceren Altuntaş Vural, Chalmers, Technology Management and Economics

Degree project report 2024
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 31 772 1000

Assessing the Environmental Impact of Waste-to-Energy Transportation
Diego Alejandro Rivera Contreras
Elisabetta Gemelli
Department Of Technology Management And Economics
Chalmers University of Technology

Abstract

The thesis, titled "Waste Management's Carbon Challenge: Energy Recovery vs. Transportation," examines the environmental and economic implications of Waste-To-Energy (WTE) road transportation. Authored by Elisabetta Gemelli and Diego Alejandro Rivera Contreras at Chalmers University of Technology, the research digs into the sustainability of transporting waste for energy recovery versus the traditional use of landfills. It assesses the carbon footprint and the economic impact of utilizing WTE facilities, contrasting these with the environmental consequences and financial costs of landfill usage. Furthermore, the study explores the adoption of Hydrotreated Vegetable Oil (HVO) as an alternative fuel to reduce the transportation sector's carbon emissions, thereby offering a comprehensive analysis of both environmental and economic spheres within waste management logistics.

Waste-to-Energy, Logistics, Carbon Footprint, Hydrotreated Vegetable Oil, Environmental Impact, Landfill, Waste Management.

Acknowledgements

We would like to express our deepest gratitude to all those who have supported us throughout the development of this thesis.

First and foremost, our heartfelt thanks go to our supervisor, Ceren Altuntaş Vural. Her guidance, insightful feedback, and continuous support have been invaluable. Her expertise and encouragement have made a significant difference in our journey, and we are profoundly grateful for her mentorship.

To our friends and families, their encouragement and belief in us have been a constant source of strength and motivation. Their presence have been essential not only during the thesis but also throughout our studies. Even though they were far away, we could always feel their love and support close to our hearts. We could not have done this without them.

A special thanks to our company supervisor, Antonia Fraga. Her daily support, invaluable advice, and profound professional insights and knowledge have enriched our research. Her feedback and steadfast dedication have been the cornerstone to our success, and we are deeply grateful for having you as an inspiring mentor and an integral part of our journey.

Lastly, to all our colleagues at Ewals Cargo Care, we are immensely thankful. Their willingness to assist us with our queries, their collaboration, and the amazing environment they have created have been essential to our development. Your support and solidarity have truly made this journey enjoyable and rewarding.

Thank you all for being an integral part of this achievement.

Diego Rivera & Elisabetta Gemelli, Gothenburg, June 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BEVs	Battery Electric Vehicles
BTU	British thermal units
CAGR	Compound Annual Growth Rate
CO2	Carbon Dioxide
CO2-e	Carbon Dioxide equivalent
CV	Calorific Value
ECC	Ewals Cargo Care
ERP	Enterprise Resource Planning
FTL	Full Truck Load
HDVs	Heavy-duty vehicles
HVO	Hydrotreated Vegetable Oil
IBA	Incineration Bottom Ash
LCA	Life Cycle Assessment
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
PM	Particulate matter
QESH	Quality, Environment, Safety and Health
SCM	Supply Chain Management
WTE	Waste To Energy
H&W	Hydro and Wind power

Contents

List of Figures

List of Tables

1
Introduction

In our dynamically evolving global landscape, efficient waste management is crucial for realizing circular and sustainable goals. This report presents an overview of a current challenge within the waste transportation sector, encompassing its context and importance, while acknowledging existing limitations, which will be elaborated upon later. The report delineates the specifics of the issue to guide a targeted analysis, beginning with the background about waste and the transportation related to it.

1.1 Background

The rationale behind undertaking this thesis stems from the recognition that, despite being a sizable industry, the freight sector faces challenges in achieving its sustainability objectives (International Energy Agency, 2018). In an industry where consumer preferences are largely influenced by efficiency and economic considerations, the significance of sustainability is gradually emerging as a prominent concern. Despite efforts in environmental conservation, such as the utilization of innovative practices to reduce CO2-e emissions, these initiatives are currently limited to specific regions due to regulatory constraints (Dzioba et al., 2021).

Furthermore, while significant progress has been made with the adoption of railways and maritime shipping, attention must also be directed towards road transport. Avoiding it entirely is often not feasible, as trucks typically handle at least the first and the final leg of deliveries. Hence, there is a pressing need for solutions to enhance sustainability within road transport (European Comission, 2023).

More specifically, the complexities of transportation in the waste management industry will be examined, with an emphasis on the logistics of transporting waste, to Waste to Energy (WTE) facilities. Establishing the sustainable superiority of this business in terms of benefits over drawbacks is essential. This entails proving that the practice of transporting WTE facilities offers greater sustainability compared to alternatives such as leaving waste in landfills (Korbut et al., 2023) or exporting it to other countries (Hummel, 2023). By thoroughly examining factors such as environmental impact, resource utilization, and long-term sustainability, this research aims to provide evidence supporting the viability and effectiveness of this approach.

Finally, there has been a notable shift in the transportation industry's efforts to achieve sustainability, with an emphasis on the use of alternative fuels to reduce environmental impact and meet stakeholder expectations for cleaner energy sources. This thesis examines Hydrotreated Vegetable Oil (HVO) as a well-known alternative fuel and compares its advantages and viability to conventional diesel derived from oil. This study attempts to determine whether such alternative fuels truly offer a more beneficial, sustainable answer for the transportation industry by investigating the economic and environmental effects of adopting HVO compared to regular diesel.

1.1.1 Waste to Energy

In Europe, waste management utilizes four primary methods: recycling, biological processing, energy recovery, and landfilling. One way to reduce landfill dependency is exploring strategies for enhancing energy recovery practices, emphasizing the importance of converting waste into energy as a sustainable waste management solution (Avfall Sverige, 2022).

Energy recovery, recognized as a clean and environmentally friendly waste treatment method, involves converting non-recyclable waste into energy. This process aligns with the EU Waste Directive and the Swedish Waste Ordinance (European Environment Agency, 2022), considering waste incineration with efficient energy recovery as a form of recycling. In Sweden, energy it is a significant part of waste management, accounting for nearly half of all household waste treated. It notably contributes to the country's district heating systems, making Sweden a leading nation in Europe for energy recovery from waste (Avfall Sverige, 2022).

WTE is a central aspect of energy recovery, leveraging the combustion of waste materials at high temperatures to produce steam. This steam, in turn, powers turbines to generate electricity, with some facilities also utilizing the heat for district heating systems. This process not only contributes to reducing landfill volumes but also plays a crucial role in minimizing environmental pollution and fostering the production of renewable energy from waste (European Environment Agency, n.d.), showcasing a sustainable approach to waste management and energy generation. The adoption of these practices has significantly reduced European energy expenses and dependency on fossil fuels, while at the same time increasing environmental sustainability by lowering landfill usage and reducing CO2-e emissions (Thabit et al., 2022).

1.1.2 Landfill use

Landfill use refers to the practice of depositing waste in specified land areas. This method leads to the creation of leachate, posing a risk of soil and water contamination, and emits landfill gas, exacerbating air pollution. Additionally, landfilling influences eutrophication by increasing the concentration of mineral salts and nutrients in bodies of water, a phenomenon driven by both natural occurrences and human activities like agriculture (Brennan et al., 2016).

Multiple studies about waste management methods, such as landfilling, incineration and composting, the most used one is landfill use or "open dumping" since is the cheapest option in many countries, in the short term. For example in Canada, the incineration option costs 48.54 CAD/tonne whereas the landfill option has a costs of 32.85 CAD/tonne (Assamoi & Lawryshyn, 2012).

In other countries such as, Switzerland, Germany, the Netherlands, Sweden, Austria, Denmark and Belgium report landfill usage below 5% of the waste produced (Brennan et al., 2016). The situation is different in other parts of Europe, as seen in Figure 1.1. The representation of landfill waste including Malta, Greece, and Romania, who have a landfill utilization rate ranging from 75% to 85% (European Environment Agency, 2024b).

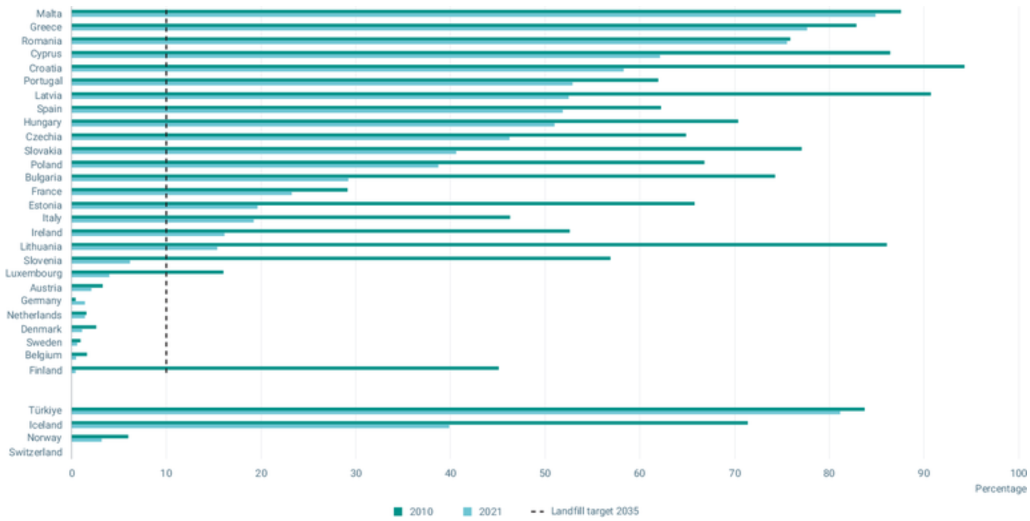

Figure 1.1: Development in landfill rate of municipal waste in European countries in 2010 and 2021 (European Environment Agency, 2024b)

A primary objective of the European Union's waste policy is the reduction of waste directed to landfills. From 2010 to 2020, the EU-27 saw a decrease in landfill rates from 23% to 16%, despite an overall increase in waste production. During this period, the volume of waste landfilled dropped by 27%, translating to 106 kg less waste per capita annually in the EU. Significant strides have been made in diverting certain types of waste, like household waste, away from landfills. Nonetheless, there has been a notable increase in the landfilling of sorting residues, which has doubled since 2010 (European Environment Agency, 2024a).

The EU Waste Hierarchy is a strategic framework, shown in Figure 1.2, that aims at guiding waste management practices to minimize environmental impact and promote sustainable resource use. It classifies waste management approaches into five levels, prioritizing them from most to least preferred. Prevention is at the pinnacle, focusing on reducing waste generation through decreased consumption, improved

Figure 1.2: European waste hierarchy. From European Commission (n.d.)

product design, and the promotion of reuse. Following prevention, reuse encourages the repeated use of products or materials without significant processing. Recycling then processes materials into new products, including both mechanical and chemical recycling techniques. Recovery, which includes energy generation methods like incineration or anaerobic digestion, comes next. Lastly, disposal, involving landfilling or incineration without energy recovery, is the least favored option due to its environmental risks such as groundwater contamination and methane emissions (European Parliament & Council of the European Union, 2018).

Within this hierarchy, landfilling is particularly discouraged due to its severe environmental impacts, underscoring its position as the least desirable method (Directorate General for Environment, 2022). Conversely, WTE technologies, categorized under recovery, are promoted as they help reduce the volume of waste directed to landfills by converting waste into energy, thereby alleviating some of the environmental concerns associated with landfilling. This structured approach not only addresses waste management pragmatically but also aligns with broader environmental sustainability goals by advocating for resource efficiency and reduced environmental impact (European Economic and Social Committee, 2017).

1.1.3 The Current State of Waste Logistics

Across the EU, road transportation accounts for 76.4% of the total freight, substantially more than every other inland mode of transportation; together, inland waterways and railroads carry less than 25% of the total (Persyn et al., 2019). Waste transport is not particularly different on this matter.

The management of solid waste presents a critical logistical challenge, compounded by increasing waste generation and often insufficient infrastructure for its effective management (Del Carmen Munguía-López et al., 2020). Global waste generation in 2017 surpassed the 20 billion tonnes mark, which translates to 2.6 tonnes per capita (Maalouf & Mavropoulos, 2022). An estimation presented by Maalouf and Mavropoulos (2022) suggest that the Municipal Solid Waste (MSW) represent approximately 2.7 billion tonnes. Their research established that he expected increase would be 260%, while the MSW will have an average increase of 35%. Globally, MSW management is being reevaluated as a strategic supply chain problem, where integration across collection, separation, transportation, and disposal phases is essential for maximizing efficiency and environmental sustainability (Mohammadi et al., 2019).

Furthermore, optimizing operational efficiency is highlighted by the development of complex vehicle routing models for MSW collection, which include multiple gather sites, transfer stations and different kind of vehicles using time windows (Son & Louati, 2016). By reducing overall travel distances, carbon emissions, and investment expenses, these models aim to meet the urgent demand for more environmentally friendly collection strategies. Adaptable solutions in waste management logistics have been highlighted by the implementation of such models in urban settings, which have shown notable reductions in operational times and environmental impact.

1.1.4 Road Freight

While there have been instances of successful adoption of sustainable transportation solutions, the advancement of sustainable freight options has been steady. Regardless of the existence of numerous sustainable transportation alternatives, the global road freight sector remains predominantly dependent on fossil fuels, with sustainable options representing less than 5% of the overall usage (Browne et al., 2022).

1.1.4.1 Carbon Footprint in Truck Delivery

The transport sector's CO2-e emissions persist in their upward trajectory, as highlighted by Lammgård and Andersson (2014). Currently, 95% of the energy utilized in the transport sector originates from oil-based sources (Browne et al., 2022). In order to achieve the global sustainability objective of achieving net zero emissions by 2050, significant changes are imperative, particularly within the transport market and its fuel sources. Moreover, the potential reduction in CO2-e emissions through the adoption of more sustainable fuels is overshadowed by the continuous surge in demand (Browne et al., 2022).

Transportation currently accounts for approximately 8% of CO2-e emissions in Europe. Within that, road transport is the leading contributor, responsible for 87% of emissions, with heavy and light-duty vehicles accounting for 11% (European Environment Agency, 2023b). This is bringing heightened attention to their significance, since freight transport in Europe alone generates an estimated 47,500 tonnes of CO2-e annually (European Environment Agency, 2023b).

Additionally, environmental sustainability has emerged as a critical concern for diverse stakeholders. Environmental factors encompass practices such as employing trucks with lower emissions standards and implementing Environmental Management Systems (Lammgård & Andersson, 2014). Transport carriers face pressure from customers, which serves as the primary driver prompting them to assess the environmental performance of their transport operations (Rossi et al., 2013).

Consequently, environmental sustainability must serve as the cornerstone for all strategic decisions going forward. Hence, it can be inferred that the transport industry urgently requires transformative measures to align with stakeholder expectations and contribute towards achieving global sustainability objectives. It is necessary to take into account a range of alternative fuels in order to close the gap between the various strategies targeted at cutting carbon emissions in the transportation sector. HVO is a highly promising environmentally friendly alternative that can be utilized for fuel vehicles in a seamless and sustainable approach.

1.1.4.2 HVO

The research and use of alternative fuels are now essential in the effort to lessen the effects of climate change as well as make the shift to a more environmentally conscious and sustainable energy landscape. Out of all of these options, HVO stands out as a potentially effective replacement for traditional diesel because it combines the benefits of the environment, operational effectiveness, and compatibility with the existing infrastructure (Szeto & Leung, 2022). In order to meet net-zero emissions targets and decrease the carbon footprint of the transportation industry and other industries that depend on diesel, this shift is not just an option but a requirement (Centre Tank Services Ltd, 2023).

Made from vegetable oils or animal fats, hydrotreated vegetable oil is a form of renewable diesel fuel. These oils and fats are hydrotreated during the production process to remove oxygen and turn them into hydrocarbons. The fuel produced by this process has various advantages for the environment while being chemically comparable to traditional diesel derived from petroleum (Mikkonen, 2008).

HVO has the potential to cut greenhouse gas emissions by up to 90%, which is one of the strongest arguments in favor of its adoption over diesel (Centre Tank Services Ltd, 2023). In the fight against climate change, this sharp decline is needed since it allows industries dependent on diesel engines to continue operating while significantly reducing their environmental impact. Furthermore, HVO is a feasible and accessible option for immediate implementation without the need for modifications or investments in new technologies because it is compatible with current diesel engines and fuel distribution infrastructure.

1.1.5 Economic Impact

The establishment and operation of WTE facilities, as well as the logistics involved, require thorough evaluation of economic feasibility and efficiency. The vital significance of these elements in guaranteeing the sustainability and feasibility of WTE programs, waste and truck logistics, and landfill utilization is highlighted in this section.

First and foremost, WTE facilities' financial viability is critical. In addition to managing trash properly, these facilities also need to do it in a manner that is economically feasible. Research shows that the technology employed, quality of the waste, and the operational efficiency attained throughout the process all play a major role in the WTE facilities' economic success. The income from producing energy and potential byproducts like metals and other recyclables must be weighed against the capital, operating, and maintenance expenses in a thorough economic analysis (Azis et al., 2021).

Second, there are substantial financial obstacles associated with the waste collection and transportation logistics, which require a fleet of vehicles. The overall budget for waste management systems includes a sizeable amount for employees, fuel, and maintenance of vehicles. These expenses may be reduced with efficient routing and scheduling, improving the waste management system's financial sustainability. Studies demonstrate the advantages of using sophisticated logistics planning instruments that may minimize expenses and optimize routes (Abdel-Shafy & Mansour, 2018).

Furthermore, the economics of waste management heavily depends on the strategic use of landfills. Landfills are sometimes thought of as the ultimate option for disposing of waste, yet there are significant financial costs associated with their construction and upkeep. The economics of landfill use include long-term environmental monitoring and aftercare expenses. Good landfill management may reduce these expenses and improve the economy's overall performance (Eunomia Research & Consulting Ltd., 2024).

Lastly, there are other economic factors to take into account when producing and using HVO as an alternative fuel source. The viability of incorporating hydrogen-based organic matter into waste management and logistics processes is contingent upon the profitability of HVO production, the accessibility of raw materials, and the market's inclination towards cleaner fuel substitutes. To ascertain if HVO is feasible in lowering the environmental effect of logistical activities, economic evaluations must take these aspects into account (Melero et al., 2012).

1.2 Purpose

The purpose of the research is to examine the trade-offs between the transportation of waste to WTE incineration plants, focusing on the emissions from both. The study will assess whether the environmental benefits of transporting waste significant distances to WTE facilities, potentially using HVO as a cleaner fuel alternative, outweigh the emissions incurred during transportation.

The goal of this research is to synthesize the environmental and economic implications, providing a comprehensive analysis of both spheres. The study seeks to offer insights into how environmental sustainability can be achieved without compromising economic viability, highlighting how interconnected sustainable goals and economic prosperity are. The goal is to evaluate different advantages and disadvantages of this operations and bring up all the possible variables that can have an impact on taking a decision it's convenient to import waste to Sweden.

1.2.1 Environmental Impact Assessment

The topic involves conducting a thorough examination of the environmental impact associated with waste transportation, specifically focusing on carbon footprint and emissions. This analysis extends to comparing the environmental performance of biofuels powered vehicles, mainly HVO, with that of traditional diesel engine vehicles within the framework of a sustainable supply chain. Given its limited availability and the feed stock mix required for its clean production, it remains relevant for the study. If all the vehicles would switch to HVO there would be not enough to cover the market.

The assessment covers multiple facets, including the route taken for waste transportation. It evaluates whether the importation of waste is genuinely sustainable or if it results in increased pollution, due to increased transportation. This aspect considers factors such as the distance travelled, mode of transportation, and associated emissions, aiming to determine the overall environmental sustainability of waste transport practices.

1.2.2 Cost Analysis Assessment

Evaluating the economic aspects of waste transportation for energy conversion necessitates the execution of a thorough cost-benefit analysis. This analytical process is crucial for understanding the financial dynamics associated with the transportation done to convert waste into energy. The primary objective is to determine the economic feasibility of the additional operations, considering various factors that may influence costs and profits.

1.3 Research Question

Research Question 1: What are the environmental impacts associated with waste transportation compared to the benefits derived from energy generation through waste incineration?

Research Question 2: What are the economic effects of transporting waste to WTE facilities for the stakeholders in the supply chain, in comparison to the costs associated with transporting waste to landfills?

1.4 Limitations

This section outlines the limitations of the study, addressing areas where data may be incomplete or findings less conclusive. It excludes Battery Electric Vehicles (BEVs) due to the limited and preliminary nature of available data, ensuring the study focuses on more robust areas. Public perception issues, such as community acceptance of waste transportation for energy conversion, are acknowledged but not explored in depth as they merit a separate study. The research does not delve into risk management or contingency planning for waste transportation hazards like accidents and spillages, nor does it include a Life Cycle Assessment (LCA), focusing instead on other specific research objectives. Market development is also outside the scope of this thesis, which centers on supply chain management within Europe. Geographical limitations mean the study concentrates on a representative sample from Europe rather than encompassing global waste management practices. Finally, the limitations of using HVO as a singular solution in transportation are discussed, emphasizing the need for diversified energy resources to avoid over-reliance on any single source.

1.5 Outline

The research begins with an introduction to the challenges of waste management within the freight sector, particularly emphasizing the sustainability issues associated with road transport. It sets the stage for a detailed examination of waste logistics and the environmental and economic impacts of utilizing WTE facilities versus traditional landfill use. The introduction outlines the thesis's objectives and the significance of exploring sustainable waste management practices.

The main body of the text, split into several chapters, dives into theoretical frameworks and empirical findings. The "Frame of Reference" chapter elaborates on WTE processes and their implications, discussing environmental, economic, and social impacts and integrating these with sustainable supply chain practices. Subsequent chapters detail the research methods used, present empirical data, and analyze the findings to assess the viability and impacts of WTE strategies in Sweden, comparing these against traditional methods like landfilling.

The document concludes with discussions that synthesize the research findings, comparing them with existing practices and literature, followed by conclusions that summarize the significant insights gained, highlighting all the trade-offs that this specific market faces in order to be successful. Recommendations for future research and improvements in waste management practices are provided, aiming to enhance sustainability and economic viability in the sector.

2
Frame of reference

The aim of this chapter is to explore the theory behind waste management and sustainable supply chain practices, delving into two distinct yet interconnected realms. The theoretical framework presented in this chapter is divided into two main sections, each addressing critical aspects of waste management and supply chain logistics. The first section embarks on a comprehensive examination of waste-to-energy processes, encompassing a multifaceted analysis of its functionality, socio-environmental impacts, and economic considerations. This section seeks to unravel the intricate workings of WTE systems, shedding light on their operational mechanisms and evaluating their efficacy in mitigating environmental degradation while concurrently addressing energy needs. In the second section, the focus shifts towards supply chain logistics within the context of waste management. Here, emphasis is placed on elucidating the logistical challenges inherent in waste transportation, with a particular emphasis on reverse logistics, cross-border logistics and the economical impact.

2.1 Waste to Energy

The WTE concept accordingly to Kalair et al. (2021), involves the conversion of different types of waste materials, including MSW, biomass, and bio-waste, into usable energy forms such as electricity, heat, or fuel. This process is crucial for addressing contemporary global concerns such as air pollution, climate change, and plastic waste (Office of Energy Efficiency and Renewable Energy, n.d.). By converting waste into energy, the environmental impact of waste disposal is reduced, and sustainable energy sources are generated. The author Kalair et al. (2021), emphasizes the importance of waste to energy conversion in fostering a circular economy, where the take, make, use, reuse, and recycle steps are promoted (United Nations Environmental Programme, 2019).

2.1.1 Categorization

The WTE process involves various technologies and methods to convert waste materials into energy. Some of the key methods discussed by Gomez et al. (2019) include:

- Combining waste materials with carbon monoxide (CO) to create nano-particles that can be added to plastic, concrete, and coatings to improve performance and efficiency (Cernuschi et al., 2012).

- Utilizing microorganisms to remove carbon from CO or natural gas and then mixing the collected pure carbon with oxygen and hydrogen to yield biopolymer substances (Gomez et al., 2019).
- Converting nitrogen oxide into HNO, which has various applications in medical, industrial, and commercial settings (Paolocci et al., 2007).
- Employing technologies such as direct water injection and selective catalytic reduction to reduce emissions of pollutants like nitrogen oxides (NOx) in vehicle exhaust (Okumuş & Kökkülünk, 2023).
- Using lightning to clean the atmosphere by converting greenhouse gases into less toxic forms, which then fall to the earth as raindrops (Brune et al., 2021).

These methods and technologies demonstrate the diverse approaches to WTE conversion, highlighting the multiple nature of this process and its potential to address environmental challenges while generating sustainable energy.

2.1.2 Environmental impact

The combustion of fossil fuels, such as oil, gas, coal, and biomass (Russell, 2014), is a significant source of environmental pollution, accounting for two-thirds of the emissions that contribute to both climate change and air quality degradation (Smith & Lampkin, 2019). These activities release a variety of hydrocarbons into the atmosphere, which are central to the challenges of air pollution and climate change. Among the pollutants, greenhouse gases (GHGs) play a relevant role in warming the Earth's atmosphere. The primary GHGs associated with fossil fuel combustion include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur dioxide (SO2), carbon monoxide (CO), ozone (O3), and chlorofluorocarbons (CFCs) as shown in Figure 2.1 (Willoughby, 2002). In addition to these, there are specific air pollutants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3) that directly impact air quality and human health (Vallero, 2021).

There are several major industries that contribute significantly GHG emissions (Miri et al., 2022), with the combustion of fossil fuels accounting for the greatest share at 77%. The contributions from industrial processes (8%), waste management (3%), and agriculture (10%) (Madsen, 1995). Waste-related emissions have evolved significantly over time in the European Union. In particular, waste-related greenhouse gas emissions were estimated to be 5.2 million tonnes in 2008; by 2021, however, emissions were expected to be decreased to less than 4.4 million tons. The reduction occurs in the solid waste industry, which leads to the waste management category in GHG emissions. Wastewater and, to a lower degree, emissions from waste incineration also contribute to GHG emissions (Karak, 2012).

Particulate matter (PM) pollution is mostly caused by human activity and comes from a variety of sources. The combustion of fossil fuels in automobiles, the running of fire kilns (Asif, 2009), other industrial processes (Eckbo, 2009), and the operation of power plants are important examples of these (Demirel, 2014). Furthermore increasing PM pollution are agricultural practices including stubble burning, the

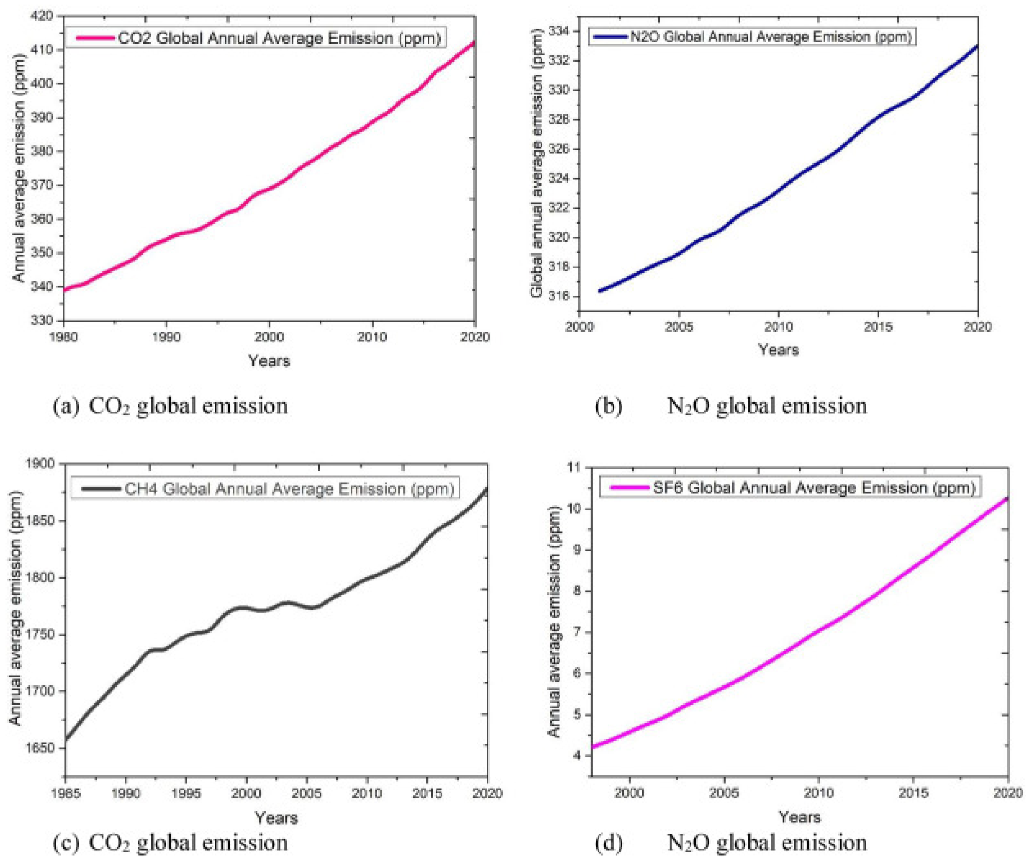

Figure 2.1: Atmospheric concentrations of major GHG emissions. From Kalair et al. (2021)

.

usage of fireworks, dust from roadsides, burning of household waste, and some industrial processes. Among the main causes of PM pollution, burning coal for power generating and home heating stands out (Rahimnejad, 2023).

WTE processes offer a significant opportunity to mitigate environmental impacts by reducing GHG emissions by an estimated 160 million tonnes annually (WtERT, n.d.). This does not imply that emissions are entirely absent. These technologies are projected to contribute approximately 2% to global electricity supply by 2030. In typical WTE facility 65% of CO2-e emissions are biogenic, highlighting its role in transforming waste management practices away from traditional landfilling—which can release methane, a potent greenhouse gas, into the atmosphere—to more sustainable, energy-producing alternatives (Klinghoffer et al., 2013). According to Kalair et al. (2021), the CO2-e emissions across different WTE processes vary.

However, incinerating waste is not an efficient use of resources. The majority of municipal waste, which includes items like paper, plastic, and glass, could be redirected towards recycling or composting programs rather than being destroyed. Over 90% of the materials sent to incinerators and landfills have the potential for a second life through these means. Utilizing waste for electricity generation not only undermines conservation efforts but also encourages the production of more waste. This practice often correlates with lower recycling rates in countries that prioritize waste incineration (Muznik, 2018).

The comparison of carbon footprints reveals differences between waste-to-energy conversion (WTEC), fossil fuels, and traditional renewable. This comparison highlights the environmental impacts of various energy sources, as shown in Figure 2.2.

Technological advancements have significantly enhanced the environmental performance of WTE facilities, allowing them to surpass the Maximum Achievable Control Technology (MACT) standards with a considerable margin of safety (Ohio Environmental Protection Agency, n.d.). These improvements have led to a drastic reduction in dioxin emissions from WTE plants, ensuring compliance with, and often exceeding, the stringent regulations set by environmental protection authorities.

An interesting comparison highlights the efficiency of WTE facilities in managing dioxin emissions: operating a WTE plant for a year produces the same amount of dioxins as a mere 15 minutes of fireworks, according to research by Themelis (2007). Furthermore, it's notable that about 65% of CO2-e emissions from WTE plants are biogenic, suggesting a more environmentally sustainable option compared to traditional energy sources. This data underscores the significant advancements in WTE technology towards environmental protection standards.

"The conversion of waste into watts is a holy grail for the planet's human civilization. Waste to energy conversion technologies allow us to utilize waste heat instead of producing more electricity and GHG gases to accomplish the same task. Waste to energy conversion is the first step toward sustainable living." (Kalair et al., 2021)

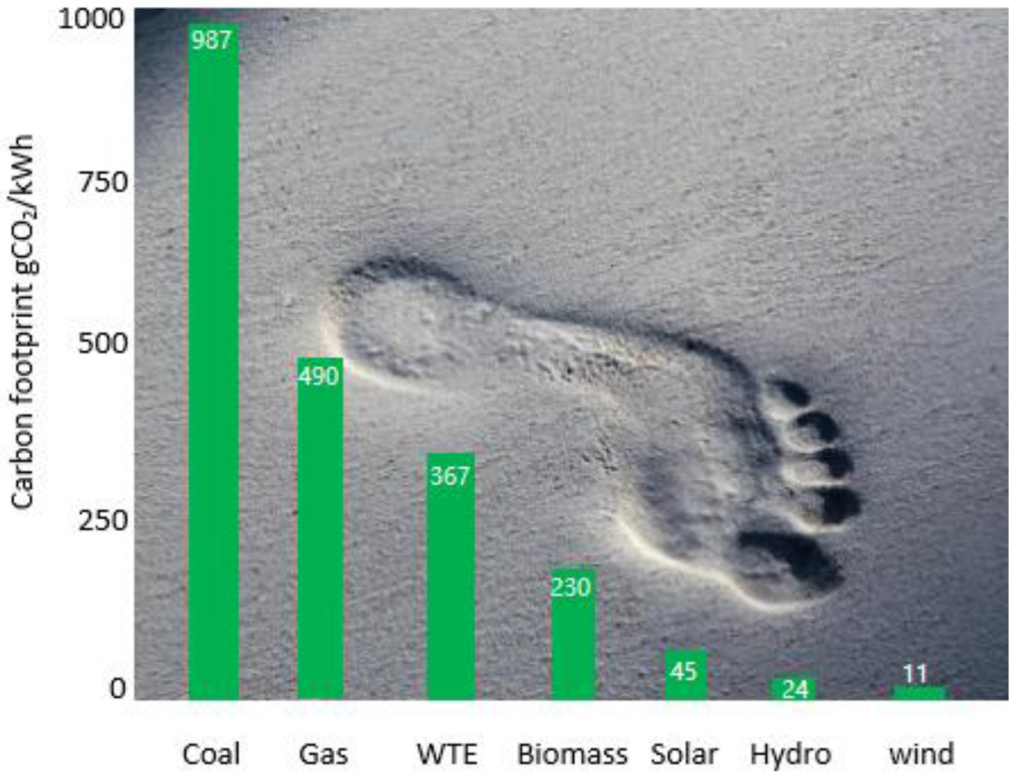

Figure 2.2: Carbon footprint values for various energy resources. From Kalair et al. (2021)

However, promoting incineration as "waste-to-energy" often tout it as a renewable energy source contrasts sharply with truly renewable sources such as wind, solar, or tidal energy, which derive from endless natural cycles. Waste, in reality, originates from the consumption of finite resources—minerals, fossil fuels, and trees harvested at rates far beyond sustainable levels and circularity (Ellen Macarthur Foundation, n.d.). Redirecting subsidies from incineration towards eco-friendly and energy-conserving practices, like recycling and composting, could offer a more sustainable and environmentally responsible investment (Giacomazzi, 2021).

2.1.3 Social impact

In the context of municipal waste management, local authorities often resort to disposing of waste in remote, barren areas outside urban centers. This practice leads to the accumulation and decomposition of garbage, which releases harmful gases into the environment (Fazzo et al., 2017). The presence of decomposing waste not only deteriorates the visual landscape of towns but also poses significant health risks due to the emission of toxic fumes. Furthermore, the unregulated burning of waste contributes to air and water pollution, as toxic materials and smoke are carried back into residential areas by wind and water currents. Plastics, a global component of municipal waste, present a unique challenge as they find their way into the human body through the consumption of contaminated food, posing severe health risks (Downs et al., 2019).

At the same time, incinerating waste poses significant health and environmental risks, as it inevitably leads to the emission of harmful pollutants. Despite advancements in technology, these processes still release dangerous substances into the air, soil, and water, which subsequently enter the food chain. Incinerators are known to emit carcinogens and fine particulate matter that can severely impact human health (Sharma et al., 2013), including causing reduced lung function, heart irregularities, heart attacks, and even premature death (Fundació ENT, 2015).

In this context, a notable disparity exists between the major polluters and the communities that withstand most of pollution's adverse effects. Wealthy and developed countries (García-Galán et al., 2013), particularly those within the Organisation for Economic Co-operation and Development (OECD) (Organisation for Economic Co-operation and Development, n.d.), are often the largest contributors to environmental pollution. These countries possess advanced technologies that significantly impact the environment through the emission of pollutants, including particulate matter (Sinha, 2019), greenhouse gases, and plastic waste. Conversely, underdeveloped and economically disadvantaged countries (Hunter, 2018) are disproportionately affected by these pollutants, facing greater health risks and environmental degradation without the means for effective mitigation.

The revised Waste Shipment Regulation by the European Commission signifies an essential step towards environmental responsibility and the reduction of global waste mismanagement (European Comission, 2024). Recognizing the severe impacts of transporting waste to non-OECD countries, the regulation aims to curtail the movement of waste that these countries are incapable to handle due to outdated technology and insufficient infrastructure (Jaynes, 2023). Such limitations often lead to the excessive use of landfills, which not only harms the local environment but also contradicts global efforts towards sustainable waste management. The policy underscores a shift from treating waste as mere refuse to viewing it as a resource that should be managed responsibly within the EU to minimize the ecological footprint of waste disposal (European Parliament, 2022).

Furthermore, the new measures focus on enhancing control over waste exports, requiring non-OECD countries to demonstrate their capability to manage waste in an environmentally sound manner before they can receive shipments. This includes adhering to international labor and workers' rights conventions, reflecting an approach to environmental justice and human health (European Comission, 2024). By setting stricter criteria for waste export and bolstering regulations within its member states, the EU aligns itself with a broader commitment to mitigating the adverse impacts of waste on global ecosystems and promoting a circular economy. These updated regulations not only aim to prevent the exploitation of weaker waste management systems in poorer countries but also to ensure that waste treatment does not contribute to the further degradation of the planet(European Parliament, 2022).

2.1.4 Landfill use

Reducing, reusing, and recycling waste is emphasized in environmental campaigning as a way of minimizing its negative effects on the environment. Waste that has been disposed of is supposed to be collected in containers or bins and then taken to landfills. But there are disadvantages to both landfilling and composting: while composting produces greenhouse gases, landfilling can contaminate groundwater, which has an impact on our food, water, and air systems (Leavitt, 2023). Poorly managed waste can lead to the release of black carbon, affecting air quality and human health, with approximately 7 million people dying yearly from exposure to fine particulate matter (United Nations Environment Programme, 2020). Annually, over two billion tonnes of trash are generated globally, with a significant portion not being safely managed. This mismanagement leads to severe environmental and health risks, including contamination of drinking water and the spread of diseases. The solution lies in minimizing waste generation and maximizing material and energy recovery from waste (United Nations Environment Programme, n.d.).

2.1.5 Economic Impact

The economic effects of WTE technologies are examined in this chapter, with particular attention paid to the investment and operating costs as well as the wider

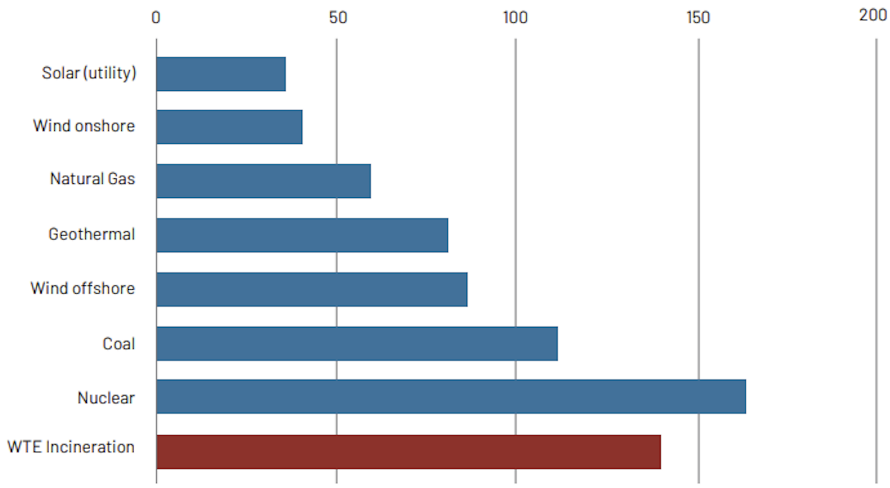

Figure 2.3: Global levelized cost of generation (USD/megawatt hour). From Lazard (2020a, 2020b)

ramifications for the energy markets. It provides information about the financial factors influencing the adoption of WTE.

2.1.5.1 Cost in Waste to Energy

Waste to Energy industries have costs related to waste processing, which includes the costs of getting waste ready for converting it into energy. Sorting waste is the first step in the preparation process; recyclable and non-combustible materials are separated from those that can be incinerated or converted into energy. These steps are necessary to guarantee the energy recovery process's effectiveness, security, and environmental responsibility. On the other hand, they result in higher operating costs for WtE facilities, including employees, technology, and sorting and processing equipment. These costs also include the recycling or disposal of materials that cannot be used to produce energy. These initiatives aim to maximize the usefulness of waste inputs, optimize the energy conversion process, and respect by environmental norms and laws (Leavitt, 2023).

Moreover, it's also relevant that incineration is a notably expensive method for managing waste and generating energy (Kumi & Shah, 2019). Burning waste for energy recovery is more costly compared to most existing energy sources when considering the same unit of energy, as shown in Figure 2.3.

Specifically, WTE incineration costs are highlighted as being significantly higher than those of natural gas, coal power, solar power, and wind energy:

- Natural Gas: WTE incineration costs are more than double those of natural gas. This comparison underlines how traditional fossil fuel sources, despite their environmental impacts, remain economically more viable for energy generation compared to incineration (US - Department of Energy, 2019).

- Solar and Wind Power: WTE incineration costs nearly four times more than solar power and wind energy. This stark contrast showcases the economic efficiency and sustainability of renewable energy sources over waste incineration (Lazard, 2020a, 2020b).

Compared to renewable energy sources, waste incineration is not only less sustainable due to its environmental impacts but also less economically feasible. For more sustainable and cost-effective waste management solutions, pointing out that municipalities can significantly reduce both waste management and electricity generation costs by adopting a zero-waste approach and utilizing solar power as an energy source (Anderson et al., 2016). This approach is presented as a more financially and environmentally sustainable alternative to WTE incineration, highlighting the potential savings and benefits of prioritizing recycling, composting, and the use of renewable energy sources (Makavou, 2021).

There are also capital costs that need to be taken in consideration when it comes to waste to energy plants. For example, the Amager Bakke incinerator in Copenhagen, notorious for its excessive financial demands, reportedly required over 500 million euros for its creation. This significant expenditure was further amplified by expensive technical setbacks, including a problematic installation of combustion furnaces that led to an extra cost of 13 million euros and a delay of seven months in the construction timeline (Nicastro, 2017). Additionally, after operating for three consecutive years beyond the permissible dioxin emission levels since 2014, the Danish Environmental Protection Agency mandated the facility to adhere strictly to legal emission standards by implementing extra emission surveillance and ongoing purification methods (Recupero, 2019).

This scenario is not unique to Denmark; several countries, including Sweden, Denmark, the U.K., Germany, the Netherlands, South Korea, and China, have encountered the dilemma of investing too heavily in Waste-to-Energy (WTE) facilities. These investments often lead to underutilized capacities, known as plant overcapacity, posing significant financial and environmental challenges (Shapiro-Bengtsen et al., 2020). In some cases, this overcapacity compels municipalities to import waste from neighboring areas, inadvertently turning their facilities into waste repositories for other regions. This situation further complicates the sustainability and economic viability of such waste management strategies (Jofra Sora, 2013).

2.1.5.2 Costs of landfilling

Capital costs in the context of waste management facilities landfills, encompass the initial investments required to develop, construct, and commission these facilities. These costs are substantial as they cover a wide range of expenditures, including but not limited to purchasing land, obtaining necessary permits and approvals, construction of the facility itself, and installation of specialized equipment for waste processing or energy recovery. For WTE facilities, capital costs also include the technology for waste incineration, gasification, or anaerobic digestion, along with systems for energy generation and emission controls. In the case of landfills, capital costs would cover the construction of the landfill site, including any engineered liners, leachate collection systems, and gas capture infrastructure to comply with environmental regulations. The magnitude of these capital expenditures significantly influences the economic viability and planning of waste management projects, requiring careful financial analysis and planning to ensure sustainability and compliance with regulatory standards (United States Environmental Protection Agency, 2014) .

Another category of costs when it comes to landfilling are, post-closure costs. Those are expenses incurred after a landfill has reached its capacity and is officially closed. These costs are critical for ensuring the long-term safety and environmental integrity of the site. They cover a range of activities necessary to manage the site's impact on the surrounding environment, including:

- Leachate Management: managing the leachate, a liquid that drains or 'leaches' from a landfill, involves treatment systems to prevent it from contaminating local water sources (Kremen, 2023).
- Landfill Gas Management: even after closure, landfills continue to emit gases -primarily methane and carbon dioxide- as the waste decomposes. Collecting, flaring, or utilizing this gas for energy requires infrastructure that must be maintained (United States Geological Survey, n.d.).
- Groundwater Monitoring: to detect any potential contamination from the landfill, groundwater wells around the site are monitored regularly. This ensures that any leachate migration is identified and addressed promptly.
- Structural Maintenance: this includes maintaining the integrity of the landfill cap (Duffy, 2011).
- Environmental Monitoring: besides groundwater, monitoring may include checking for soil contamination and ensuring that the landfill does not adversely affect local wildlife (United States Environmental Protection Agency, 2024b).

These activities can span several decades, requiring a significant financial commitment from waste management authorities or companies responsible for the landfill (Walsh, 2023). The goal is to mitigate any negative environmental impacts and protect public health, which underscores the importance of incorporating these long-term costs into the initial planning and budgeting for landfill sites.

Taxes are an other costs that needs to be considered. The concept of a singular "landfill tax" is somewhat misleading due to the intricacies and variations across jurisdictions. Specifically, looking at the United Kingdom, for example, the structure includes different rates like a 'standard rate' and a 'lower rate'. Additionally, VAT (European Commision, n.d.) may be levied on top of the landfill tax, which can vary depending on the VAT status of the business, and local municipalities might impose further charges (Thunder Said Energy, 2024).

Landfill taxes have exhibited an average compound annual growth rate (CAGR) of 8% across various regions, as shown in Figure 2.4. By 2022, the average fee for landfill disposal has escalated to approximately €70 per ton, marking a significant increase from €50 per tonne a decade earlier and €30 per tonne two decades prior. This upward trend in landfill taxes illustrates the relentless rise in costs associated

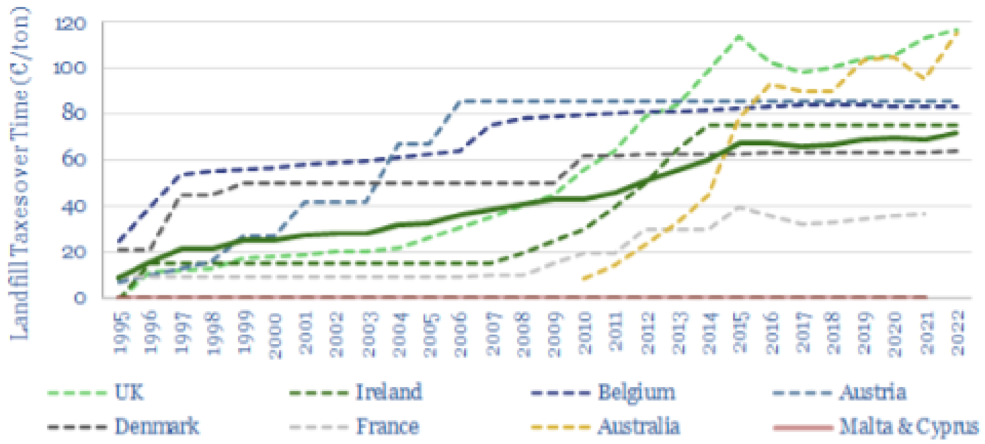

Figure 2.4: Tax increase in landfilling. From Thunder Said Energy (2024).

with waste disposal, emphasizing the notion that taxes, including those on landfill, invariably trend upwards. Notably, apparent decreases in fees, when viewed in a global context, often result from foreign exchange fluctuations rather than actual reductions in local currency terms Energy (Thunder Said Energy, 2024).

And finally, there are costs related to lost opportunities. Opportunity costs associated with landfilling waste regard the myriad benefits or value that could be derived from other potential uses of the resources or land dedicated to waste disposal. This concept is multifaceted, including:

- Alternative land uses: land dedicated to landfills misses out on being used for agriculture, development, or recreational spaces. This choice implies a cost, as these alternative uses could provide economic growth, environmental preservation, or social benefits (Biotrux, 2023).
- Environmental considerations: the environmental footprint of landfilling—ranging from pollution to habitat disruption—represents a significant opportunity cost. Alternatives like recycling, composting, or employing waste-to-energy methods could mitigate these impacts, leading to better conservation of resources and ecosystem preservation (Maletz et al., 2018).
- Resource recovery: disposing of waste in landfills means losing out on the potential to recover valuable resources. Recycling, composting, and energy recovery can transform waste into usable materials or energy, presenting an opportunity cost in terms of lost resource value (United States Environmental Protection Agency, 2023).
- Economic implications: the direct and indirect costs of landfilling, such as transportation, operations, and environmental remediation, pose opportunity costs against potential savings or revenues from adopting more sustainable waste management solutions (Maletz et al., 2018).
- Social impact: the presence of landfills can adversely affect local communities, impacting quality of life through noise, odors, and reduced property values.

Alternative waste management strategies could offer social benefits by alleviating these negative impacts (Vasarhelyi, 2024).

2.1.5.3 Revenues of Waste to Energy

WTE plants primarily earn revenue through two channels: gate fees charged for accepting waste and the sale of electricity produced from this waste to the power grid (Lim et al., 2019). The amount of electricity that can be generated—and thus the revenue potential—is directly influenced by the facility's energy conversion efficiency and the calorific value (CV) of the waste processed (United States Environmental Protection Agency, 2024a). Essentially, the more combustible the waste (e.g., plastics, paper, wood), the higher the energy output and potential revenue from electricity sales. Conversely, the presence of non-combustible materials, like glass or bricks, can lower the CV and reduce electricity generation capabilities.

Globally, the WTE market is on the rise, with significant growth projected in the coming years. The Asia-Pacific region currently leads the market, largely due to the pressing need for sustainable waste management solutions in densely populated areas. However, the adoption of WTE solutions also presents an opportunity for economic development and energy security worldwide, particularly in regions with limited space for landfills and growing energy demands (U.S. Energy Information Administration, 2023).

And finally, the newest technology allows material recovery. For example, municipal solid waste incineration (MSWI) stands as a predominant method for managing MSW in Europe, generating about 20 million tonnes of incineration bottom ash (IBA) annually. The specific composition of IBA varies with the waste it originates from, often containing recoverable materials such as ferrous and non-ferrous metals, along with glass (Šyc et al., 2020).

2.1.5.4 Revenues of landfilling

Some landfill sites optimize energy production by capturing and burning landfill gas (United States Environmental Protection Agency, 2024b), a byproduct of waste decomposition, to generate electricity. This process not only generates additional revenue by selling the electricity back to the grid, similar to incineration facilities but also utilizes a simpler method to convert waste into energy. By capturing methane gas emitted from landfill waste, it can be harnessed to power generators at a plant, thus transforming waste into energy through gasification (National Energy Technology Laboratory, n.d.-a).

In the gasification process, syngas produced can undergo further transformation into hydrogen and carbon dioxide (CO2) by introducing steam and a catalyst in a water-gas-shift reactor. The combustion of hydrogen results in producing only heat and water, allowing for electricity generation without CO2-e emissions (National Energy Technology Laboratory, n.d.-b). Additionally, hydrogen derived from coal or other solid fuels has applications beyond energy production, such as in refining oil or manufacturing products like ammonia and fertilizer. It can also be utilized to produce liquid fuels like gasoline and diesel. Gasification technology facilitates polygeneration plants capable of producing multiple outputs. Moreover, it enables efficient CO2-e capture from syngas (National Energy Technology Laboratory, n.d.-c), thus preventing its release as a greenhouse gas and allowing for its use in applications like Enhanced Oil Recovery or secure storage (National Energy Technology Laboratory, n.d.-d).

And finally, incineration facilities represent one of the most costly approaches to energy generation and waste management, placing a heavy financial strain on the communities that host them (Kim & Jeong, 2017). The Amager Bakke incinerator in Copenhagen serves as a notorious example of such fiscal challenges. Numerous municipalities have found themselves in debt due to the high costs associated with incinerators (Nicastro, 2017). Furthermore, some local governments are locked into lengthy contracts, obligating them to supply a fixed amount of waste for decades to ensure the recovery of investment expenses. A case in point is Harrisburg, Pennsylvania, which faced severe financial difficulties after updating its incineration plant in 2011, leading it to become the largest U.S. city to file for bankruptcy at the time. This situation underscores the economic risks and long-term financial commitments involved in adopting incineration as a waste management solution (Muznik, 2017).

2.2 Logistics

According to Chopra and Meindl (2015) logistics is an fundamental part of supply chain management, which entails organizing, implementing, and managing the seamless transportation and storage of products, services, and associated data from the point of origin to the site of consumption in order to satisfy client demands. Many tasks are included in this field, including as supply and demand planning, inventory management, transportation, warehousing, material handling, order fulfillment, logistics network design, and management of third-party logistics service providers.

Delivering the right products to the right place at the right time in the right condition is the primary objective of logistics, together with cost optimization and customer value delivery (Inbound Logistics, 2023). It is fundamental to the global economy due to how it helps companies take advantage of globalization by increasing productivity, cutting expenses, and boosting customer satisfaction.

Within the context of Supply Chain Management (SCM), the shift in logistics' perception from a cost center to a strategic tool for competitive advantage highlights the evolution of global business practices (Tukamuhabwa et al., 2021). This is particularly clear in the case of industry globalization, where successful supply chain integration and management are crucial to the process.

2.2.1 Reverse Logistics

While returns of goods was discussed back in the 40s (Beckley & Logan, 1948), the term of reverse logistics was not coined until the 1992 by Stock, addressing it as the procedure for organizing, carrying out, and managing the economical and efficient movement of raw materials, completed goods, inventory for use in production, and associated data from the point of consumption back to the point of origin for the purpose to recoup value or dispose of waste adequately (Stock, 1992).
Reverse logistics is defined as the strategic and operational planning involved in the flows of material, products, and information get managed from the point of consumption to the point of origin in the purpose of recapturing value or ensuring proper disposal. It covers not only returns of goods from final customers due to damage, obsolescence, or return; it also covers remanufacturing, refurbishing, recycling, and general product and material disposal (Hawks, 2006).

Reverse logistics is a comprehensive program that involves reducing material usage, redesigning packaging, minimizing environmental impact through transportation, and generally improving the sustainability of the supply chain (Quesada, 2003). It goes beyond simple recycling of materials or reusing packaging.

When materials or goods are transported upstream in the supply chain for any reason, as opposed to the usual forward logistics flow, reverse logistics is specifically brought into play (Jenkins, 2021). It handles recycling efforts, hazardous material, the disposal of outdated equipment, and asset recovery in addition to managing returns of merchandise for a variety of reasons, including damage, seasonal changes, and overstock.

Reverse logistics is typically a component of making sure that the business is dedicated to resource efficiency, responsibility for the environment, and sustainable business practices rather than a complement to supply chain management (Banihashemi et al., 2019). Because of this, and in contrast to the conventional linear model of supply chains, it is a characteristic of modern supply chain strategies.

2.2.2 Waste Logistics

As per definition made by United Nations Statistical Division (1997) waste are all materials that are not created for the market so that the generator can use them in any further steps of the production, transformation, or consumption process are referred to as waste. Byproducts or leftovers from different phases of the extraction, processing, and consumption of materials fall under this category. With the exception of residuals that are recycled or reused on-site, waste usually refers to a variety of materials that the generator must dispose of. Waste can be classified as solid, biological, industrial, and household waste.

Waste collection is the process of gathering and transporting waste to a location where it will be treated or disposed of. Municipal services or other specialized organizations usually carry out this operation, which can range from undifferentiated collection,which removes all trash types at once, to selective collection, which targets a particular product type (United Nations Statistical Division, 1997).

The term "waste management" refers to an extensive array of actions taken to handle waste in an efficient and sustainable manner (United Nations Statistical Division, 1997). This covers waste collection, transportation, treatment, and disposal in addition to production and management process monitoring and control. In order to reduce waste generation, it also entails techniques like in-process changes and the encouragement of recycling and reuse.

The Waste Management Hierarchy, which is a prioritized approach to waste handling, is established by the European Parliament & Council of the European Union (2024). This hierarchy promotes a set of recommended practices, the first of which is the avoidance of waste production and is followed by material reuse. Energy recovery and other recovery operations are the next in line as ways to reprocess trash into new resources, after recycling. Land filling is one type of disposal that is thought to be the least ideal solution. This methodical strategy seeks to decrease the harmful effects of waste and encourage resource efficiency in order to advance environmental sustainability.

2.2.2.1 Cross-Border Logistics and Coordination

EU laws control waste transfers across European borders in an effort to guarantee safe waste transportation, recovery, or disposal that doesn't endanger human health or the environment (European Parliament and Council, 2021). The framework, which adheres to stringent standards and procedures, particularly with regard to hazardous waste, makes it easier for garbage to be moved within the EU for recycling or disposal (Council of the European Union, 2021).

The international treaty called the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was created to control the movement of hazardous wastes internationally, with an emphasis on preventing their transfer from developed to developing nations (United Nations, 1989). Its goal is to safeguard the environment and public health from any risks that may arise from improper handling and disposal of hazardous waste. The convention places a strong emphasis on disposing of hazardous waste as close to its source as feasible and encourages the reduction of hazardous waste generation in terms of both quantity and toxicity. It presents the Prior Informed Consent (PIC) principle, which guarantees that hazardous waste is only transported across international borders with the receiving nation's express consent. This promotes mutual understanding and openness in waste management procedures (Secretariat of the Basel Convention, 2019).

		Distribution (% of wet weight)	Water content (kg tonne^{-1})	Ash (kg tonne^{-1})	Biogenic carbon (kg tonne^{-1})	Fossil carbon (kg tonne^{-1})	Lower heating value (GJ tonne^{-1})
MSW	Paper	20	150	170	340	2	13
	Textiles	4	140	50	300	100	16
	Plastics	11	85	50	90	590	32
	Glass	5	80	920	3	3	0
	Metals	3	100	900	1	1	0
	Organic	35	700	110	150	2	4
	Other	22	250	330	220	110	8
	Total	100	352	226	191	94	9.9
SRF[a]	Paper	55	150	170	340	2	13
	Textiles	10	140	50	300	100	16
	Plastics	30	85	50	90	590	32
	Other	5	250	330	220	110	8
	Total	100	135	130	255	194	18.8

[a]The relative distribution of paper, textiles and plastic was assumed to be similar in the SRF and MSW. Additionally, five percent impurities from the "other" fraction were added to the SRF.

Figure 2.5: Average composition of European MSW. From Astrup et al. (2009)

2.2.2.2 Environmental Impact

The transportation and collection of trash have an environmental impact that contributes significantly to greenhouse gas emissions and, in turn, global warming. This is known as waste logistics. Studies like the one done by Eisted et al. (2009) quantify these emissions at various waste management phases and emphasize that fossil fuel sources account for the majority of energy consumption and greenhouse gas emissions, as seen in Figure 2.5.

The greenhouse gas emissions from waste logistics activities, such as collection, transfer, and transport, differ greatly depending on the technologies and methods selected. For example, there are significant differences in emissions when it comes to transport by private vehicles, use of drop-off containers, full-service and kerbside collection, and pneumatic collection systems (Astrup et al., 2009). In a similar vein, the mode of transportation—by land, air, sea, or road—has a noticeable influence on the total emissions profile.

The implementation of strategies aimed at reducing the environmental impact of waste logistics is needed. These include the reduction of waste transportation via private vehicles, the optimization of routes and methods for long-distance waste transport, and the enhancement of collection and transfer process efficiency. The carbon footprint of waste management systems can be greatly decreased by taking such actions (Eisted et al., 2009). The emphasis on efficiency and optimization in waste logistics not only helps to lower GHG emissions but also harmonizes waste management techniques with more general objectives related to sustainability and climate action.

It is noteworthy that the current body of research on the transportation of waste frequently fails to account for the emissions produced in the process as seen in Figure 2.6 (Astrup et al., 2009). The environmental effects of road waste transportation are

Indirect: upstream	Direct: waste management	Indirect: downstream
GWF (kg CO_2-eq. tonne^{-1} ww): High CO_2 electricity: 59 to 158 Low CO_2 electricity: 7 to 62	GWF (kg CO_2-eq. tonne^{-1} ww): 347 to 371	GWF (kg CO_2-eq. tonne^{-1} ww): High CO_2 electricity: –811 to –1373 Low CO_2 electricity: –480 to –712
GWF (kg CO_2-eq. tonne^{-1} ww): • Fuel oil provision: 0–1 • Natural gas provision: 0–2.1 • Electricity provision: High CO_2: 59 to 108 Low CO_2: 7 to 12 • $CaCO_3$ provision: 0–0.07 • $Ca(OH)_2$ provision: 0–11 • NaOH provision: 0–25 • NH_3 provision: 0–11 • Water provision: 0–0.2	GWF (kg CO_2-eq. tonne^{-1} ww): • CO_2-fossil (fuel oil combustion): 0–5.4 • CO_2-fossil (natural gas combustion): 0–15.4 • CO_2-fossil (waste combustion): 345 • CO_2-biogenic (waste combustion): 0 (GWP: 0) • N_2O emissions: 2.4–5.4 (GWP = 298)	GWF (kg CO_2-eq. tonne^{-1} ww): • Energy recovery from incineration: Substituted electricity: High CO_2: –372 to –743 Low CO_2: –41 to –82.5 Substituted heat: –446 to –631 • Management of solid residues: APC residues: 0–2.5 Bottom ash: 1.2–4.1
Accounted (unit tonne^{-1} ww): • Fuel oil provision: 0–2 l • Natural gas provision: 0–7 Nm^3 • Electricity provision: 65–120 kWh • $CaCO_3$ provision: 0–8 kg • $Ca(OH)_2$ provision: 0–12 kg • NaOH provision: 0–7 kg • NH_3 provision: 0–5 kg • Water provision: 0–1 m^3	Accounted (unit tonne^{-1} ww): • Combustion of fuel oil: 0–2 L • Combustion of natural gas: 0–7 Nm^3 • Combustion of fossil carbon in waste: 94 kg C • Combustion of biogenic carbon in waste: 191 kg C • N_2O emissions: 8–18 g	Accounted (unit tonne^{-1} ww): • Energy produced from incineration: Produced electricity: 15–30% of LHV = 413–825 kWh Produced district heat: 60–85% of LHV = 5940–8415 MJ • Management of solid residues: APC residues: 0–50 kg Bottom ashes: 226 kg
Not accounted: • Transportation of waste to plant • Pre-sorting of the waste • Provision of materials for construction of plant • Provision of heat for offices etc. • Provision of activated carbon for dioxin removal	Not accounted: • Construction of the facility • Emissions from stored waste • Emissions of trace gases	Not accounted: • Dispersively emitted gases • CO_2 uptake in solid residues • Transport of residues to treatment and disposal facilities

APC, air pollution control; GWP, global warming potential; LHV, lower heating value.

Figure 2.6: Global warming factors for waste incineration. From Astrup et al. (2009).

often overlooked in favor of waste management systems' operational efficiency and logistics. An underestimate of the total ecological footprint of waste management techniques may result from this omission. Closing this gap is imperative to creating a comprehensive understanding of waste logistics sustainability.

2.2.3 Impact from transport

Trucks and other heavy-duty vehicles (HDVs) contribute significantly to CO2-e emissions from road transportation in the European Union, posing a serious threat to the environment. On August 14, 2019, the HDV CO2-e emission standards regulation went into effect with the goal of lowering these emissions by establishing targets for newly registered lorries annually (European Comission, 2023). A 15% reduction is needed starting in 2025, and it will increase to a 30% reduction in 2030 and beyond, as shown in Figure 2.7. This regulation introduces incentive mechanisms for zero- and low-emission vehicles to encourage the adoption of greener technologies. Large lorries account for over 73% of all CO2-e emissions from HDVs. The revision of the policy has not been approved yet.

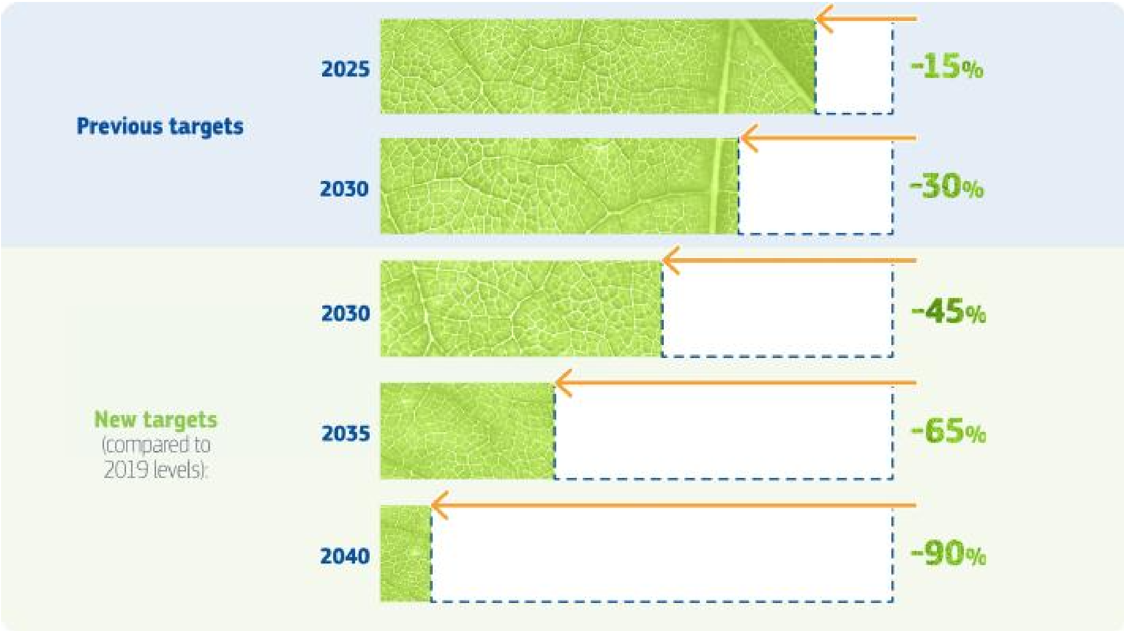

Figure 2.7: CO2-e saving targets for EU. From European Comission (2023)

Despite the fact that greenhouse gas emissions in the EU have been steadily declining over the past ten years, CO2-e emissions from HDVs have increased yearly since 2014, with a brief decrease in 2020 because of the COVID-19 pandemic (European Environment Agency, 2023a), as witnessed on Figure 2.8. This increase is ascribed to a rise in the demand for freight transportation, which has been somewhat mitigated by efficiency gains in fuel and vehicle technologies. Achieving the European Green Deal's objective of a climate-neutral EU by 2050 will require substantial changes in the transportation sector, according to the European Environment Agency (EEA). This entails increasing energy efficiency, switching to cleaner cars, and using more effective modes of transportation.

According to the EEA's analysis, the rise in HDV emissions varies amongst Member States, with trucks contributing about 85% of these emissions (European Environment Agency, 2023a). Reversing this trend requires policy actions at the EU and Member State levels with an emphasis on decarbonizing HDVs. These include creating CO2-containing truck tolls, building electric road systems, and providing incentives for zero-emission urban transportation.

2.2.4 Economic Impact

When discussing about waste logistics, particularly when it comes to moving waste for processing or energy conversion, it is important to look at costs, regulations, and market dynamics from a variety of angles (Mesjasz-Lech & Michelberger, 2019).

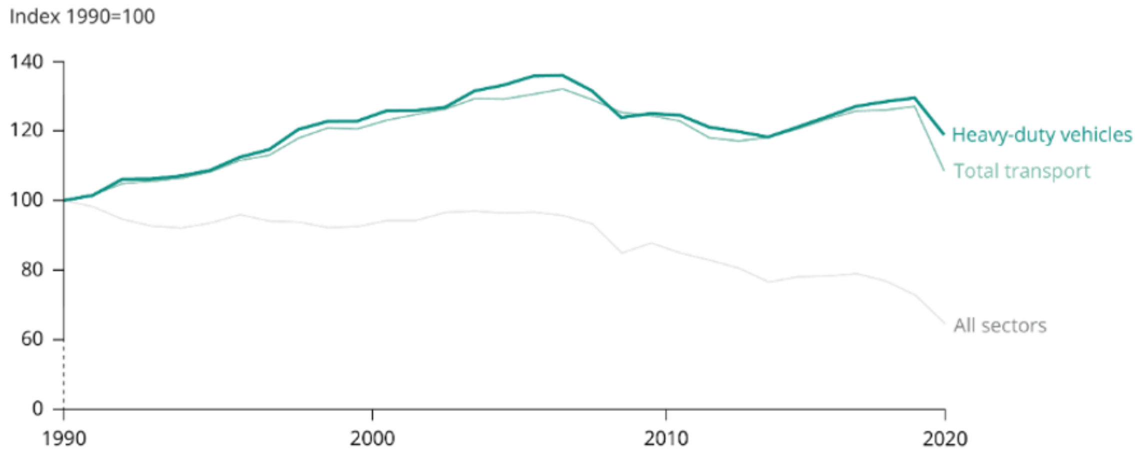

Figure 2.8: Trends in CO2-e emissions from HDV in the EU 1990-2020. From European Environment Agency (2023a).

2.2.4.1 Costs of Logistics and Transporting Waste

This section will give an qualitative overview of the costs linked to the logistics and transporting of waste.

2.2.4.1.1 Fuel Costs: One major factor in the logistics of moving waste is the cost of fuel. Historically, the main fuel used in heavy-duty transport vehicles has been diesel (Sheykin, 2023). But because they have less of an impact on the environment, alternative fuels like HVO are becoming more popular (Greenea, 2016). The fuel selection affects operating costs; alternative fuels, though potentially offering lower emissions and environmental benefits, frequently command a premium over conventional diesel.

2.2.4.1.2 Vehicle Maintenance and Depreciation: The maintenance costs of heavy-duty vehicles used in waste transportation are high and increase with the age of the vehicle and the harshness of its operating environment, which also differ depending on the type of vehicle and its source for power (Rout et al., 2022). Depending on the life-cycle and resale value of the vehicle, depreciation of these assets also affects the logistical cost.

When including HVO in the analysis, because HVO has a higher cetane number than regular diesel, the combustion process is carried out more thoroughly (Zeman et al., 2019). It doesn't contain aromatics, which are in charge of most of the hazardous nitrous oxides and tiny particle emissions present in fossil diesel, and it also has less sulfur 5 mg/kg against 10 mg/kg of standard diesel (Andreae, 2023).

2.2.4.1.3 Labor Costs: One important factor is the labor cost, which includes drivers' pay, insurance, and training (Izadi et al., 2020). These expenses may increase even more if handling hazardous materials necessitates specific training.

2.2.4.2 Legal Fees and Regulations

According to European Union (EU) regulations, nations that are unable to handle their waste domestically are required to follow stringent export guidelines, which include making sure the waste is managed sustainably. Penalties and significant legal costs may follow noncompliance (European Comission, 2024). Furthermore, the Basel Convention regulations apply to the cross-border transportation of waste, requiring compliance with international legal standards and potentially resulting in additional costs.

2.2.4.3 Additional Considerations

The implementation of vehicle maintenance programs and route optimization can have a major impact on operating costs and fuel efficiency. While routine car maintenance keeps expensive breakdowns at bay and guarantees fleet efficiency, optimized routing can cut down on needless mileage and save fuel. Fuel costs can also be decreased by encouraging and rewarding drivers for driving fuel-efficiently (Jacobson, 2020).

2.2.5 HVO

The potential for HVO to provide significant environmental benefits has made this emerging biofuel very relevant. Recent research, such as Easter et al. (2022) study, has shown that HVO, as opposed to conventional diesel derived from fossil fuels, can significantly reduce greenhouse gas emissions. Its effectiveness in reducing the effects of climate change is demonstrated by the observed variations in emission reductions, which range from 30% to 80%. This quality is especially significant since it supports international efforts to meet decarbonization goals (Julio et al., 2022). HVO is categorized as a biogenic fuel because it comes from renewable biomass sources, making it a sustainable and environmentally beneficial substitute for traditional diesel fuels (Bronić et al., 2017). By increasing the variety of fuel sources, this renewable origin improves energy security while also lowering carbon footprints.

Research has indicated that the utilization of HVO in substitution of diesel in heavy-duty trucks can effectively mitigate emissions of carbon monoxide and nitrogen oxides (NOx) (Dimitriadis et al., 2018). Further evidence for HVO's potential as a cleaner alternative comes from research showing it to have notable toxicological advantages over other fuels (Westphal et al., 2013).

The full-circle manufacturing process of HVO is one of its main advantages. A circular economy can be facilitated through the manufacture of HVO from a variety of feedstocks, such as residual fats and oils, by making use of resources that would otherwise be wasted (Da Silva et al., 2023). This feature raises HVO's sustainability profile and is consistent with the circular economy's tenets, which reduce waste and environmental impact by recycling and reusing resources.

The feedstock mix used in HVO production impacts its efficiency rates when employed as a diesel substitute in heavy-duty trucks. The choice of feedstocks is crucial to optimizing the advantages of this biofuel since it can affect the overall performance and emissions profile of HVO (Di Gruttola & Borello, 2021). It is feasible to maximize the effectiveness and environmental advantages of HVO as a diesel replacement for heavy-duty vehicles by meticulously examining the feedstock mix.

3
Methodology

This section outlines the Research Design, Data Collection and Sampling, Data Analysis and Research Quality used in the research.

In order to conduct this research, (Yin, 2014) recommends using a single case study method to study events in their real environments. Eisenhardt and Graebner (2007) mention that case studies provide detailed, real-world observations from different data sources. To explore how services are organized in the waste logistics industry, this method is appropriate.

To do so, it is necessary to present the combination of primary data gathered through interviews with stakeholders such as project managers and operations planners, and secondary data sourced from company reports, internal and external databases. The chapter describes both qualitative and quantitative analysis approaches to evaluate the data and includes a thorough environmental viability and cost-benefit analysis to assess the implications of the waste management methods. Additionally, it discusses measures taken to ensure the research's quality and integrity, enhancing the credibility of the findings.

3.1 Research Design and Case Selection

For this research a single case study is selected for the design. This is a type of research technique in which a single or limited number of cases of an event are carefully studied in order to find the complexity and nuances within real-world situations. Yin (2014) argues that case studies are especially helpful in addressing "how" and "why" questions. They offer qualitative data that can provide in-depth understanding of the research topic.

In case study research, choosing alternatives to analyze within the case is an important stage that has significant effects on the extent and quality of the results. Purposeful sampling, according to Patton (2023), is a deliberate approach for choosing cases that most closely represent the topic that is being studied. In order to ensure that the instances chosen for purposeful sampling give rich and pertinent data, precise criteria that match with the goals of the research are used to pick the cases.

The selection criteria for case studies include: relevance to research questions, which guarantees that the cases directly contribute to the study's objectives; the possibility of providing rich, detailed data for in-depth analysis and deep insights; and feasibility of access, which takes into account the practicality of obtaining necessary data.

This research employs a triangulated research design, integrating qualitative with quantitative methods to enhance the reliability and depth of findings (Creswell, 2008; Denzin & Lincoln, 2017). Triangulation in research involves using various datasets, methods, theories, and investigators to address a research question. This strategy aims to improve the validity and credibility of findings while reducing research biases. This approach not only captures rich insights but also strengthens studies by comparing data thoroughly, thereby improving the robustness of the conclusions drawn.

As outlined by Rossman and Rallis (2017), one component that distinguishes qualitative research within this triangulated framework is the researcher, who serves as the primary instrument for data collection and interpretation, establishing themselves as proactive knowledge producers. This function is significant since it requires actively interpreting data.

Also, the literature review is conducted using a variety of sources, including digital platforms such as Google Scholar, ResearchGate, and databases provided by the Chalmers Library and route data from Google Maps. Additionally, company data from Ewals Cargo Care (ECC), extracted from their databases and information systems. More specifically the ERP system has been used to define the routes combined with the Route Optimization Plan. Moreover, the Fleet Fuel Consumption report regarding environmental impact assessment, and also annual sustainability reports, were used to define sustainability goals of the company.

This strategy for literature collection is important in establishing a solid frame of reference for the study, ensuring an understanding by integrating diverse perspectives. Further guidance on implementing a triangulated research design can be found in works by Creswell (2008) and Denzin and Lincoln (2017), who emphasize the importance of methodological rigor and the need for multiple data sources to confirm and cross-validate findings.

Additionally, a fundamental aspect of the research involves analyzing real routes to quantify emissions based on various variables. Specifically, three locations are selected for a more detailed study, including calculations of distances, emissions, and discussions on transportation methods and types. This approach provides a more analytical perspective, ensuring a robust, quantitative research design.

3.1.1 Selected Routes

The selection of locations for the case study is influenced by three distinct factors: identification of largest landfills in Europe, distance between the landfills and the WTE plants, and finally ECC operations.

Firstly, identifying the largest landfills in Europe is critical for several reasons, particularly when aiming to improve environmental management and sustainability. Knowing the size and capacity of these landfills helps in planning and optimizing WTE facilities. This ensures that WTE plants are adequately scaled to handle the volumes of waste these large landfills receive, making them more effective at diverting waste from landfills to energy production. Additionally, by understanding where the largest accumulations of waste are located (Binns, 2019), policymakers and waste management professionals can implement more targeted and efficient strategies to reduce landfill use, lower emissions, and promote recycling and waste reduction.

Secondly, the distance between landfills and WTE plants as a key factor because longer routes increase emissions. It investigates whether a certain distance in Europe results in transportation emissions outweighing the benefits of energy conversion. By analyzing the farthest points in Europe, the study ensures that all shorter distances are also evaluated for their emission impacts.
And lastly, the choice of locations for ECC's operations is also influenced by their pre-existing connections in those countries, facilitating a deeper understanding and better data gathering about the logistics involved. The company's selection of operational areas is based on where they already have established partnerships, collaborations, and joint ventures.

3.2 Data collection and Sampling

The data collection for this study is organized into two principal categories: primary and secondary data. Primary data are information gathered directly by the researcher, tailored specifically to the study's objectives. The data are collected first-hand from its source, with methods including informal talks, interviews, and data obtained directly from the company software. As for secondary data, the sources include reports from companies in the WTE, fuel and H&W suppliers, providing additional context and background for the research.

3.2.1 Primary Data

The process of gathering primary data in this context involves several targeted strategies to ensure a comprehensive understanding of the company's operations and environmental impact. Firstly, conducting interviews with employees across different departments allows for a diverse range of insights into daily operations, internal processes, and potential areas for efficiency improvements. These interviews help identify specific practices that contribute to carbon output, operational challenges, and opportunities for sustainable practices.

3.2.1.1 Interviews

The interviews were semi-structured, starting with a predetermined set of questions that were anchored in the guiding questions outlined within the study's framework.

The approach allowed for flexibility during the interviews, where additional, relevant follow-up questions were posed as the discussions evolved. Three key personnel within the company were interviewed: the Strategic Oversight Specialist supervising the thesis's development, an Operations Specialist, and the company's Quality and Safety Expert.

While the foundational questions were consistent, they were tailored to tap into the expertise of each interviewee. This method leverages the strength of expert interviews, which Flick (2022) notes as a valuable complement to the existing body of literature and articles, enriching the research with firsthand insights. Semi-structured interviews are particularly advantageous in exploratory studies, as noted by Hennink et al. (2020), because they enable researchers to address gaps in existing literature and deeply explore interviewees' specialized knowledge through targeted follow-up questions.

The process of selecting interview participants was dynamic and evolved throughout the research. It was influenced by recommendations from the initial interviewees and other company employees, facilitating the inclusion of participants with critical relevance and expertise pertinent to the study's focus. The selection strategy not only broadened the scope of potential subjects but also introduced additional resources such as previous project documents, articles, and reports from external companies, thereby enhancing the research's breadth and depth.

Moreover, some informal, unstructured interviews provided an opportunity to capture insights and perspectives that might not emerge in more formal settings. Asking questions during breaks or within the flow of the workday facilitated natural conversations, often leading to the revelation of details about the company's operations, culture, and challenges. This approach allows for a broader understanding of the organization and the market, complementing the structured data collection methods with rich, qualitative insights that could significantly enhance the depth and authenticity of the research findings.

Table 3.1: Interview Details

Type of Interview	Interviewee	Experience	Date	Duration of interviews
Both	Strategic Oversight Specialist	5 years	22.01 - 29.03	6 hour
Both	Operations Specialist	2 years	12.02 - 16.02	1.5 hours
Unstructured	Regional Coordinator	3 years	15.02	0.5 hours
Both	Development Coordinator	6 years	22.01 - 26.01	2 hours
Structured	Quality and Safety Expert	8 years	05.04	0.5 hours
Structured	Energy Sector Research Specialist	13 years	21.03	1.5 hours
Unstructured	Entry-Level Commercial Associate	4 months	29.03	0.25 hours

The primary candidates selected for interviews were employees at ECC, their positions are shown in the Table 3.1.

3.2.2 Secondary Data

The selection of secondary data involves an analysis of reports from companies in the WTE, HVO, Hydro& Wind (H&W) power sectors. This approach not only includes a thorough review of publicly available industry reports and publications to understand broader market dynamics but also leverages internal company data to assess operational efficiencies and environmental impacts. By examining existing data from these sectors, the research aims to identify benchmarks performances, and understand the overall landscape.

Leveraging the Enterprise Resource Planning (ERP) system that the company uses is necessary. This system provides valuable data on resource usage, supply chain logistics, production metrics, and other operational aspects that are integral to assessing the company's overall carbon footprint. The ERP system serves as a source of real-time data that can be analyzed to understand energy consumption patterns, resource utilization rates, and waste management practices.

Lastly, the use of a carbon emission calculator helps in quantifying the company's carbon emissions. This tool integrates data from various sources, including the ERP system and insights gathered from employee interviews, to calculate total emissions. It allows the company to measure its environmental impact precisely and identify key areas where carbon reduction is feasible.

3.2.2.1 Company reports

Company reports were used to gain an in-depth understanding of the current marketplace and provide a qualitative analysis of the project's viability. Specifically, Stockholm WTE company's report provided a quantitative analysis of emissions, enabling a comparison and quantification of the impact, specifically gathering information about their WTE processes. This company was selected due to its association with ECC, facilitating data collection via their contacts and the ERP system, thereby enriching the research with real-world data and insights.

The 2023 Sustainability Reports from Neste and Vattenfall provide insights into their sustainability efforts, emphasizing the use of renewable energy sources, and the reduction of carbon emissions. Neste is commended for its important contribution to the advancement of renewable fuels and their effects on sustainability and logistics as a global leader in the production of HVO. Furthermore, Vattenfall's initiatives to increase its H&W power capacities highlight its dedication to improving sustainable energy options. Those two reports are used specifically to analyse the impact of WTE compared to different energy sources.

3.2.2.2 ERP

The ERP system implemented within the company serves as a tool for tracking data related to historical processes, client interactions, routing, and waste transportation details. Moreover, this software facilitates the creation and optimization of logistic tracks, offering capabilities to show the most efficient routes from loading points to delivery destinations. This functionality grants a pragmatic perspective on operational workflows, planning strategies, and the challenges encountered in the logistics sector, providing invaluable insights into the intricacies of logistical management and operational efficiency.

Additionally, the software deployed by the company proved instrumental in retrieving historical client data, thereby enabling a deeper understanding of cost structures, and the volumes of business handled. This capability not only facilitated an analysis of past transactions and client relationships but also provided a solid foundation for strategic planning and decision-making, highlighting the software's significant role in enhancing operational insight and financial management within the company.

3.2.2.3 Online Databases

The CO2-e emissions calculator by CarbonCare (2024) is validated and approved by S.G.S. Tecnos, S.A., adhering to the new ISO Norm 14083:2023. This norm, published in April 2023, outlines rules for calculating CO2-e emissions from transport and logistics, integrating several existing ISO standards. The calculator features detailed CO2-e reporting, emission factors adapted to ISO standards, new CO2-e value designations, inclusion of emission intensity and transshipment activities, cooling and refrigerant leaking considerations, and distance calculations based on the shortest feasible distance or great circle distances as applicable. The calculator allows for the input of various detailed specifications, such as the engine type and ferry details, affecting emission calculations. It distinguishes between different emission types: total emissions, which account for the entire life cycle from production to consumption; operational emissions, focusing on the emissions during vehicle operation; and energy provision, related to the supply of energy. These categories correspond to the well-known terms well-to-wheel, tank-to-wheel, and well-to-tank, providing a nuanced view of the environmental impact.

For HVO, prices where collected from a public database of Shell Sweden, which includes both HVO and diesel prices, which allows for an analysis of market trends, price fluctuations (Shell Sweden, 2024). This information is relevant for understanding the economic aspects of fuel choices in logistics and assessing the viability of switching to more sustainable options like HVO in response to market changes.

3.3 Data analysis

This section describes how data are treated after being obtained from various sources. Additionally, it will give a thorough examination of three routes, each of which represents a distinct circumstance in a different country. These studies shows the effects of switching to HVO on these emissions and provide data on emission volumes. Also, this chapter includes observations from staff interviews, data from the company's database, discussions with subject matter experts, and reports and websites used to estimate emissions and costs.

3.3.1 Data Categorization

The data gathered are categorized by source and type, allowing for a structured comparison and deeper understanding of relevant topics. By grouping the data according to its origin, it's possible to contrast and identify the most informative sources. The types of data include categories such as energy generation, environmental effects, and economic impacts. Additionally, the data are organized into three routes, facilitating a structured comparison of established routes and enabling data-driven conclusions.

3.3.2 Route Analysis

This section of the study focuses on the systematic analysis of data collected through various methods to explore the logistics of transporting waste to incineration facilities in Sweden. Utilizing the Eisenhardt (2021) method, this analysis seeks to draw on empirical data to construct a understanding of operational efficiencies, environmental impacts, and logistical strategies associated with the routes.

Arrangements of interviews with key employees and firsthand observations of operational procedures are used to gather primary data. This information offers a current understanding of the logistics procedures, decision-making methods, and strategic factors involved in waste management.

Secondary data sources encompass government rules on transportation and waste management, ERP systems, environmental company reports, and previously published studies on related subjects. These resources supported the initial findings and served as a benchmark for our conclusions, especially when it came to comprehending the wider effects of the transportation strategies employed.

From the information acquired from different sources, potential routes are defined and the data are structured to be analyzed and compared. This includes the modes of transport, distances carried, and emissions generated. With this, it was possible to present the following:

1. Diagram the company's current waste handling logistics route, which will be further detailed in the next chapter.
2. Determine and list possible routes for the case study.
3. Identify the routes that waste materials take to reach Stockholm's incinerator facility.

3.3.3 Calculation Procedures

The objective of the data analysis is to compare various routes and approaches in order to thoroughly assess the environmental of WTE transportation and economic effects. The main goal of this analysis are to measure carbon emissions, examine the generation of energy, and evaluate the views of sustainability and economic viability. To do so, emissions and energy generation are calculated. For the research, the unit for comparison is 27 tonnes of waste or its equivalent. The usefulness of this unit relies on the fact that, this amount optimizes transport by making it a FTL, thereby utilizing a more environmentally efficient solution (International Energy Agency, 2017).

3.3.3.1 Energy Calculation

To build a proper comparison the goal is to set a fixed amount of energy generation to directly compare the energy sources. Here, the main sources to evaluate are the WTE, oil, and H&W power.

For WTE, the company reports present a yearly amount of waste processed, combining the municipal and business waste. At, the same time they show data regarding the overall energy generation considering the whole year's production. With this information, it is possible to estimate the energy produced per tonne of waste to later normalize into the FTL trailer quantity.

Additionally, oil has a conversion rate of energy per barrel which establishes the potential energy it holds, this value obtained for the source needs to be adjusted according the actual efficiency of oil-burning power plants. This allows the identification of the amount of barrels needed to produce the same amount of energy.

Lastly, for H&W power there is no need for calculation, just rather a normalization of the amount of energy produced to align it to the proper emissions amount. The company reports show the values of CO2-e emissions directly as a ratio from the kWh produced.

3.3.3.2 Emissions Calculation

Currently, there is a need to define which of data are relevant for the respective calculations. Once the routes have been defined for all the routes, the activity data are the quantitative measurements required as inputs.

Waste transportation involves a number of variables, including fuel type, emission considerations, cargo weight, distance traveled, and mode of transportation. The data are processed with assistance from the CarbonCare CO2-e emissions calculator. Company reports, which display emissions per tonne of waste, are the source of information about WTE emissions. There is no need for further processing and the result is standardized to the unit that corresponds to a FTL.

Once the necessary number of barrels is established, government sources offer CO2-e emission estimates for calculating oil-related emissions. This is a calculation that makes use of the emission factor. The energy-producing company provides the emissions data for H&W , which are then extracted and normalized using the energy equivalent of 27 tonnes of waste.

Lastly, greenhouse gas emissions from landfilling take into account the anticipated length of time that waste would remain there. The weight of waste is used to estimate these values, which just need to be normalized to the same unit of comparison. When reaching uniformity in data and using standard units of measurement, the overall results are presented in a clear and organized manner.
e overall results in a organized manner.

To evaluate the emissions from WTE activities, it's important to include the transportation of waste, considering the potential reductions from using alternative fuels. Additionally, the emissions calculations should deduct those from landfilling, which WTE processes help to avoid. This approach yields the net CO2-e emissions for each route, facilitating a comparison with emissions derived from oil, as well as H&W. The data will be displayed in tables and graphs to clearly visualize the comparisons.

3.3.4 Economic Aspect

Given the scarce access to information, such as costs like burning waste, transportation, landfilling, and the revenues associated with those operations. The related to the actual values for the operations and investments regarding WTE activities and landifilling, the analysis for this section relies on the qualitative finding obtained from the interview. The data are processed by assessing in different categories both strategies. A scale is implemented to be used in this comparison.

On the other hand, information about fuel types is readily available on suppliers' websites, which provide historical data to facilitate comparisons with traditional fuels. This data is also used to assess the impact on transportation costs.

3.4 Research quality

Preserving the validity and reliability of data is fundamental in academic research in order to ensure the accuracy and trustworthiness of the findings (Johnson & Onwuegbuzie, 2004). While reliability refers to the consistency of the results across multiple research, validity guarantees that a study's conclusions accurately represent the real world. Increasing validity and reliability is facilitated by the triangulation technique, allowing for the utilization of many sources of data to validate findings (Johnson & Onwuegbuzie, 2004). By combining information from several sources, such as interviews, published literature, and organizational records, researchers increase the validity of their study (Johnson & Onwuegbuzie, 2004).

While replication is sometimes implied by reliability, qualitative research, which aims to comprehend a broad spectrum of experiences, challenges the idea of reliability (Johnson & Onwuegbuzie, 2004). According to Johnson and Onwuegbuzie (2004), qualitative investigations prioritize consistency in understanding data over replication. In qualitative research, triangulation is also employed to guarantee dependability by verifying results through several sources an triangulation is a technique that can be used to improve a study's validity and reliability (Johnson & Onwuegbuzie, 2004). To guarantee more validity and reliability, it is also advised to use mixed research methodologies (Zohrabi, 2013).

4

Empirical Findings

This section analyzes various factors that influence the emissions and economics of the study. Beginning with the case description allows for a clearer framing of the variables and data analyzed. One part analyses the environmental impacts of transportation using three routes to Stockholm. It highlights also the use of FTL trailers to maximize capacity and reduce trips, thereby lowering emissions. It compares emissions from conventional fuels to those from HVO, a sustainable fuel alternative. Additionally, it explores waste incineration and its CO2 emissions, with a focus on the advantages of WTE processes that convert waste into energy, cutting emissions relative to traditional oil burning and providing energy locally. Comparative tables show the emissions benefits of WTE versus traditional methods and the advantages of hybrid H&W energy over WTE. These findings impact the research and add value to the triangulated method, which aims to combine qualitative and quantitative data.

4.1 Company Overview

ECC, founded in 1906, has grown into a global logistics service provider, having its headquarters in the Netherlands. Over the decades, the company's presence has grown to include businesses in 14 countries and 31 distinct sites. Despite its global prominence, ECC maintains its roots as a family-owned business, instilling a combination of tradition and adaptation in its organizational culture. The company is focused on three product lines: full loads, part loads, and control towers. These options reflect a sophisticated approach to meeting clients' unique demands, demonstrating ECC's dedication to bespoke solutions in this evolving logistics world. Understanding ECC's historical trajectory, industry emphasis, and strategy development offers the groundwork for understanding the motivations driving is actively seeking avenues to contribute to a positive and sustainable transformation in the world.

A detailed analysis of carbon reduction strategies is part of the company's strategic roadmap, which highlights HVO potential as a cleaner fuel substitute. The company's investment in sustainable practices and compliance with international environmental targets will be significantly influenced by the results of this evaluation. The goal is to not only integrate even more HVO into their operations but also to establish a standard for responsibility in environmental management in the logistics industry.

4.2 Routes

The main focus of this section is showing various routes and the different variables that play an important role in this study. First of all, the distances between landfills and WTE plants. Then, the specific transportation methods employed, detailing the volume of waste transported, the resultant energy generation, and the corresponding emissions across different energy sources such as WTE, fossil fuels, and renewables. Additionally, emissions associated with landfilling are examined, along with how HVO can offer valuable solutions within this framework. To support this analysis, specific routes will be presented, allowing for the quantification of collected data. In other to define and quantify those variables, three routes are taken in considerations, with three different origins: London, the current route being used, Madrid and Istanbul, the new routes to analyze.

Figures 4.1, 4.3, 4.2 illustrate the routes, orange is used to represent the sections performed by truck, pink for ferries and green is used for trains.

4.2.1 London to Stockholm - Current state

Currently, there is one route that is used by ECC. The route starts with road transportation from London to Purfleet, then Purfleet to Zeebrugge via ferry. The waste is transported to Gothenburg via another ferry leg, and the journey ends with a last road trip to Stockholm. Based on the data collected from each activity carried out in 2023, the transportation operation occurs out 1,321 times a year on average. This frequency is indicative of the significant operational and logistical work needed to maintain this level of service.

The Table 4.1 shows the amount of emissions associated to the distances for each trip leg, also presenting what are the emissions in case of using HVO instead of traditional fuel.

The operation uses a multimodal transport process, with segments delivered by road and ferry, thereby rendering a simpler task to transport waste materials across international boundaries.

In London, trucks are loaded in order to begin the transportation journey. From there, there are several phases of the trip to Stockholm:

- Initial Road Transport: Trucks depart London to deliver the waste to the Purfleet ferry port. The distance traveled is 23 kilometers by road.
- Ferry Crossing 1: This is the first of two ferry crossings, where waste is shipped from Purfleet to Zeebrugge. The distance traveled is 230 kilometers by sea.
- Ferry Crossing 2: The cargo departs Zeebrugge and travels by ferry to the port of Goteborg. The distance traveled is 1226 kilometers by sea.

- Final Road Transport: The waste is transported by truck from Goteborg to Stockholm as the final section of the route. The distance traveled is 481 kilometers by road.

Table 4.1: Transportation Details: London - Stockholm

Mode of Transport	Origin	Destination	Distance (km)	CO2-e Emission (Kg)	CO2-e Emission HVO (Kg)
Road	London	Purfleet	23	36.59	2.93
Ferry	Purfleet	Zeebrugge	230	319.61	319.61
Ferry	Zeebrugge	Goteborg	1226	1683.14	1683.14
Road	Goteborg	Stockholm	481	715.61	57.25
Total			**1960**	**2754.96**	**2062.93**

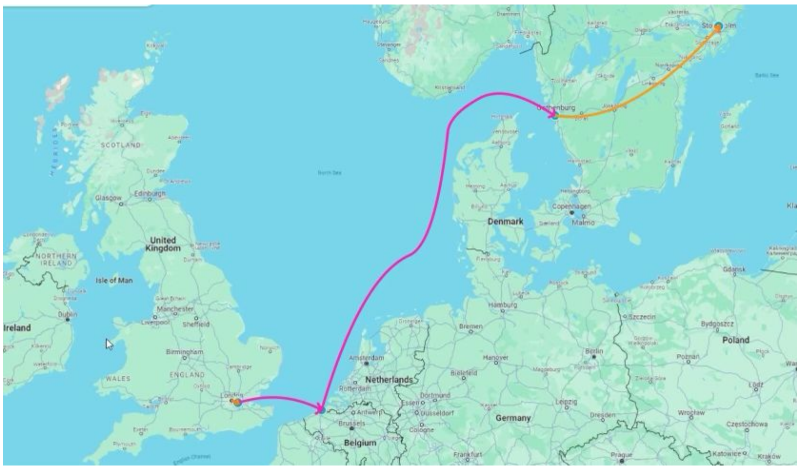

Figure 4.1: Route 1: London - Stockholm

Also, it's important to notice that FTL delivery method is used for all trailers, which guarantees effective utilization of transportation capacity and reducing environmental effect per unit of waste transported.

In accordance with the FTL approach, every trailer must be loaded to the fullest legal extent before departure. The number of trips needed to transport the entire volume of waste is decreased in large part thanks to this strategy. The operation can attain greater levels of efficiency by optimizing the quantity of waste transported on each trip. This is because it reduces the amount of time lost to loading and unloading, as well as the administrative burden of organizing and overseeing several smaller shipments. Additionally, FTL transport makes logistics coordination simpler, enabling easier scheduling and route planning.

By lowering the carbon footprint associated with each unit of waste transported, the FTL approach helps achieve sustainability goals from an environmental perspective. Through trailer capacity optimization, the operation reduces the number of required trips, which in turn lowers overall fuel consumption and related GHG emissions. This fuel consumption decrease contributes directly to lessen the transportation process's overall environmental impact. Furthermore, by increasing the effectiveness of logistics operations and encouraging the use of fewer resources for a given amount of waste transported, the FTL method is in line with a wider range of environmental objectives.

4.2.2 Route from Spain

An additional route has been outlined in this study to enhance the comparison, which includes road travel from Madrid to Bilbao, then sea travel to Zeebrugge via ferry, continuing the travel to Gothenburg using the same transportation mode, and finally road travel to Stockholm.

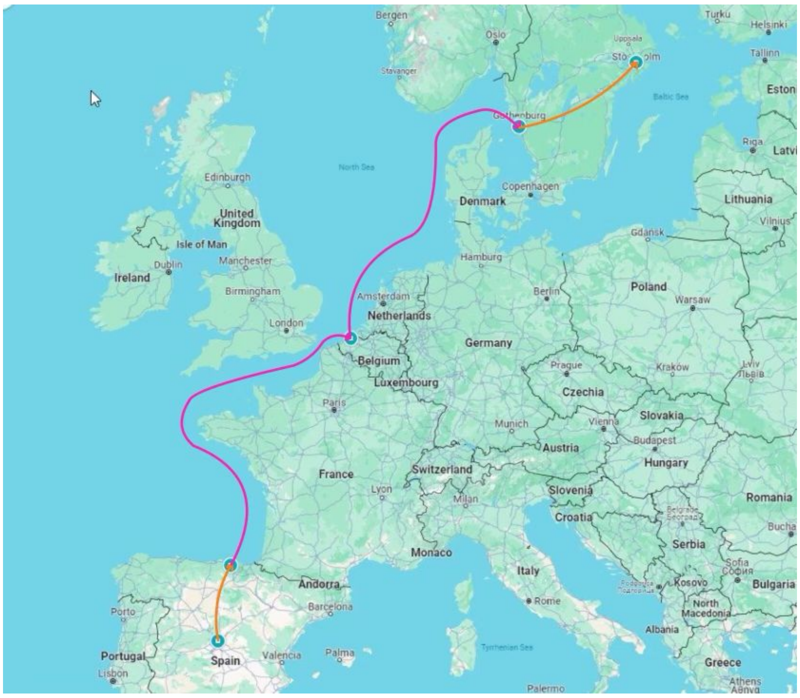

Figure 4.2: Route 2: Madrid - Stockholm

Figure 4.2 illustrates the route from Spain, orange is used to represent the sections performed by truck and pink for sea transport done by ferry. This route represents a total of 886 kilometers by truck and an additional 2552 kilometers by ferry, this information is taken from the ERP system owned by the logistics company. The Table 4.2 shows the emissions associated with each leg of the journey, comparing the traditional fuel emissions to those that would result from using HVO.

Table 4.2: Transportation Details: Madrid - Stockholm

Mode of Transport	Origin	Destination	Distance (km)	CO2-e Emission (Kg)	CO2-e Emission HVO (Kg)
Road	Madrid	Bilbao	405	603.61	48.29
Ferry	Bilbao	Zeebrugge	1326	1820.81	1820.81
Ferry	Zeebrugge	Goteborg	1226	1683.14	1683.14
Road	Goteborg	Stockholm	481	715.61	57.25
Total			**3438**	**4823.17**	**3609.49**

4.2.3 Route from Turkey

The last route, designed for this study, starts from Istanbul, taking the train to Curtici, Romania, and then the waste continues its way by road to Gdansk. The waste is shipped by ferry from Gdansk to Karlskrona, and finally to Stockholm via road again.

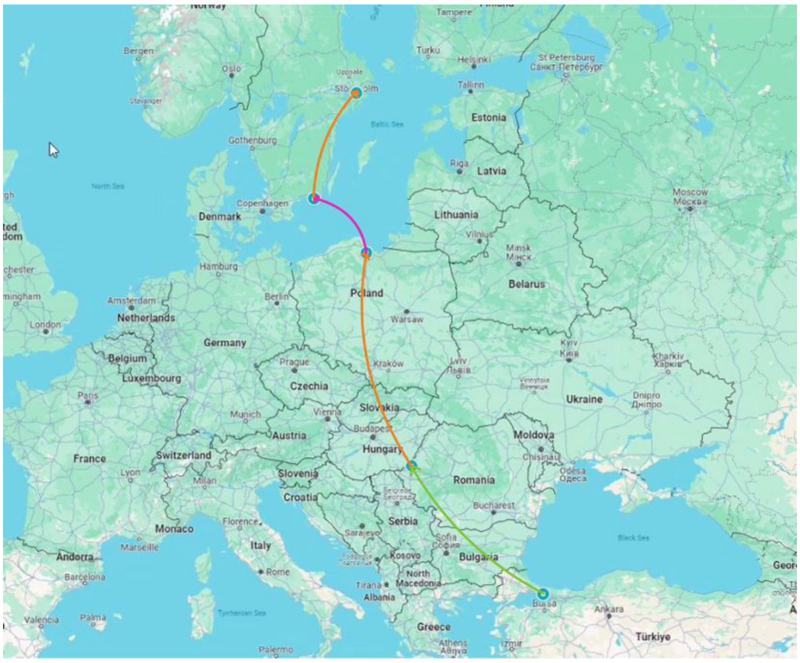

Figure 4.3: Route 3: Istanbul - Stockholm

Figure 4.3 illustrates the route described from Turkey, orange is used to represent the sections performed by truck, pink for sea transport done by ferry and green is used for trains. With 1280 km being covered by the train, 320 km done with the ferry. While the rest is done by truck which represents 1718 km.

The Table 4.3 details the emissions for each segment of the trip, highlighting the differences between traditional fuel emissions and those using HVO as an alternative.

Table 4.3: Transportation Details: Istanbul - Stockholm

Mode of Transport	Origin	Destination	Distance (km)	CO2-e Emission (Kg)	CO2-e Emission HVO (Kg)
Train	Istanbul	Curtici	1280	788.27	788.27
Road	Curtici	Gdansk	1232	1829.06	146.32
Ferry	Gdansk	Karlskrona	320	443.54	443.54
Road	Karlskrona	Stockholm	486	723.05	57.84
Total			**3318**	**3783.92**	**1435.98**

4.3 Waste Incineration and CO2-e Emissions

One of the primary methods that waste treatment activities contribute to carbon dioxide emissions is through the incineration of waste, especially plastic waste. The strategies for reducing the amount of waste that needs to be burned, such as improving sorting and recycling practices, are highlighted as ways to lessen these emissions. Moreover, using carbon dioxide capture and storage technology is being explored as a potential means of reducing emissions. According to the report's quantification of emissions, every tonne of waste processed results in about 441 kilograms of CO2-e being released into the atmosphere. These initiatives converted a significant amount of waste into energy source in 2022. In particular, they handled approximately 428,000 tonnes of municipal residual waste and 458,000 tonnes of business residual waste.

In 2022, the energy produced by this waste conversion process comes to 2,230 gigawatt-hours (GWh). The main uses of this energy are to generate electricity and heat for the neighborhood district heating system, which is key for cities. It improves energy security and lowers reliance on fossil fuels. These WTE techniques provide an important amount of energy. The heat generated is thought to be sufficient to cover the annual energy needs of about 208,119 residential households. This highlights the potential of WTE systems to manage waste effectively and supply a substantial number of households with a consistent source of energy.

From the report, each tonne of waste processed results in about 441 kilograms of CO2. Which means that for 27 tons (the amount transported by a full truck load):

$$\text{Emissions from 27 tonnes of waste} = 27 \times 441 \text{ kg} = 11,907 \text{ kg or } 11.907 \text{ tonnes } CO_2 \tag{4.1}$$

4.4 Energy Generation: WTE vs. Oil

From the Stockholm WTE company report, it's noted that the WTE process produced 2,230 gigawatt-hours (GWh) of energy in 2022 from handling significant amounts of municipal and business residual waste. To calculate the energy generated from 27 tonnes of waste (the amount transported by a full truck load), one first determines the energy produced per tonne using the total annual waste processed, and then calculates the energy for 27 tons, in order to compare it with oil emissions:

$$\begin{aligned} \text{Total waste handled} &= 428,000 \text{ tonnes (municipal)} \\ &\quad + 458,000 \text{ tonnes (business)} \\ &= 886,000 \text{ tonnes.} \end{aligned} \tag{4.2}$$

$$\text{Energy produced per tonne} = \frac{2,230 \text{ GWh}}{886,000 \text{ tonnes}} \approx 0.002517 \text{ GWh/tonne} \tag{4.3}$$

The total energy produced from 27 tonnes of waste is calculated as follows:

$$\text{Energy from 27 tonnes} = 27 \times 0.002517 \text{ GWh/tonne} \approx 0.067959 \text{ GWh} \tag{4.4}$$

Energy within a barrel of oil is about 1700 kWh, according to U.S. Department Of Energy (2020). A barrel of oil carries approximately 680 kWh of effective energy when operating efficiency of oil-fired power plants is taken into account, which is approximately 40% on average, Feng (2023) provides information on this efficiency rate, which shows that these plants lose a substantial amount of energy throughout the conversion process.

To find how much oil is needed to produce 67.959 MWh:

$$\text{Oil needed} = \frac{67.959\ \text{MWh}}{0.68\ \text{MWh/barrel}} \approx 100\ \text{barrels} \tag{4.5}$$

The emissions from burning oil depend on the type and quality of the oil. Generally, burning a barrel of oil emits about 0.43 tonnes of CO2-e (United States Environmental Protection Agency, 2024c). Therefore:

$$\text{Emissions from 100 barrels of oil} = 100 \times 0.43\ \text{tonnes CO}_2\text{/barrel} = 43\ \text{tonnes CO}_2 \tag{4.6}$$

From the report, each tonne of waste processed results in about 441 kilograms of CO2. Which means that for 27 tons:

$$\text{Emissions from 27 tonnes of waste} = 27{\times}441\ \text{kg} = 11,907\ \text{kg or about 11.907 tonnes CO}_2 \tag{4.7}$$

To visualize better data, a summary is provided in table 4.4.

Table 4.4: Comparative Analysis of Energy Production and Emissions

Description	**Value**
Energy produced from 27 tonnes of waste	67.959 MWh
Oil equivalent	100 barrels
Emissions from oil to produce equivalent energy	43 tonnes CO_2
Emissions from burning 27 tonnes of waste	11.907 tonnes CO_2

This analysis shows a significant difference in CO2-e emissions between using WTE processes versus traditional oil burning for the same amount of energy produced.

4.5 WTE vs. H&W

Similarly to above, in this section an analysis is conducted to estimate the emissions produced by generating the same amount of energy that WTE plants produce, by incinerating 27 tonnes of waste, 67,959 kWh, equivalent to a full truckload. This analysis uses data from one of Sweden's largest H&W providers, which reports emissions of 69 grams of CO2-e per kilowatt-hour (gCO2e/kWh) from a combination of both energy sources (Vattenfall, 2024).

$$\text{Energy in kWh} = \text{Energy in GWh} \times 10^6 = 0.067959 \times 10^6 = 67,959\ \text{kWh} \tag{4.8}$$

$$\text{CO2e (g)} = 67,959 \text{ kWh} \times 69 \text{ g/kWh} = 4,689,171 \text{ g} \quad (4.9)$$

$$\text{CO2e (kg)} = \frac{\text{CO2e (g)}}{1000} = \frac{4,689,171 \text{ g}}{1000} = 4,689.171 \text{ CO2e} \quad (4.10)$$

Table 4.5 presents a summary of the collected data. It is evident from the table that emissions associated with H&W are less than half of those attributed to WTE, when comparing the same amount of energy produced.

Table 4.5: Comparative Analysis of Emissions

Description	**Value**
Energy produced from 27 tonnes of waste	67.959 MWh
Emissions from H&W	4.689 tonnes CO_2
Emissions from burning 27 tonnes of waste	11.907 tonnes CO_2

4.6 Landfilling Emissions

Landfilling is a significant source of GHG emissions, primarily due to the anaerobic decomposition of organic materials which produces methane (CH4), a greenhouse gas. This section quantifies the CO2-e emissions from landfilling 27 tonnes of mixed municipal solid waste, utilizing data and emission factors derived from recent studies on landfill emissions (Manfredi et al., 2009). This facilitates the comparison between landfilling and WTE. Specifically, in the final section of this chapter, a detailed comparison of emissions from landfilling and WTE will be implemented.

According to Manfredi et al. (2009), the emissions from conventional landfilling processes can vary significantly based on the management and technology employed. For a conventional landfill, the average direct emissions are approximately 300 kg of CO2-e per tonne of waste.
To calculate the total CO2-e emissions from landfilling 27 tonnes of waste, the following formula is used:

$$\text{Total CO2e Emissions} = \text{Emission Factor} \times \text{Amount of Waste} \quad (4.11)$$

$$\text{Total CO2e Emissions} = 300\,\text{kg CO2e/tonne} \times 27\,\text{tonnes} = 8100\,\text{kg CO2e} \quad (4.12)$$

Thus, landfilling 27 tonnes of mixed waste would result in approximately 8100 kg of CO2-e emissions. This result will be used in the study to be compared with the emissions caused by WTE operations.

4.7 Route Comparison

To gain a comprehensive view of environmental impacts, it's relevant to systematically analyze and compare various routes across different geographical contexts, detailed in the provided Table 4.6. This approach considers diverse transportation modes including train: truck, and ferry, specific to each route.

The Table 4.6 shows the amount of emissions divided by country. More specifically, the section on Transportation details the emissions produced by transportation from various route locations to Stockholm, using different transportation methods. Another metric in the Table 4.6 is the HVO Saving, which represents the potential emission reductions achieved by using HVO instead of traditional fuels in road transportation. This change reflects a significant shift towards greener, more sustainable fuel options, quantifying the environmental benefits of this. The WTE section quantifies the emissions released during the process of generating energy and heat from burning waste in Sweden. Additionally, the Table 4.6 considers the impact of not leaving waste in landfills. The Landfilling metric indicates the emissions avoided by using waste for energy production instead of landfilling.

Finally, the Transportation Contribution is evaluated, which shows the proportion of total emissions attributable to transportation in the WTE process. The Table 4.6 assesses the impact of transport-related emissions relative to the overall emissions from converting waste to energy, underlining the significant role transportation plays in the overall environmental footprint of waste management.

CO2-e Emissions (kg)	**United Kingdom**	**Spain**	**Turkey**
Transportation	2,755	4,823	3,784
HVO Saving	- 692	- 1,214	- 2,348
Waste-to-Energy	11,907	11,907	11,907
Landfilling (Prevented)	- 8,100	- 8,100	- 8,100
Total	5,870	7,416	5,243
Transportation Contribution	35%	49%	27%

Table 4.6: Emissions according to the different routes

Additionally, it's important to not only compare emissions across different countries but also to understand how these compare to other energy sources. In this context, Table 4.7 is particularly useful. It presents a comparative analysis of the emissions from WTE processes against those from oil-based energy production.

The table 4.7 quantifies the total emissions generated by WTE and contrasts them with those from oil, highlighting the environmental benefits of WTE in terms of emission reductions. It provides the difference in percentage reductions, offering a clear metric to understand the efficiency of WTE compared to more traditional, and often more polluting, oil-based methods.

CO2-e Emissions (kg)	United Kingdom	Spain	Turkey
WTE Total	5,870	7,416	5,243
Oil	43,000	43,000	43,000
WTE vs Oil (Reduction)	- 86%	- 83%	- 88%

Table 4.7: Emissions: Oil vs WTE

Lastly, Table 4.8, extends the comparative analysis to another dimension by contrasting WTE emissions against those from H&W energy sources. This comparison is similar to the one provided between WTE and oil but focuses on the renewable sector, highlighting the differences in emissions between a waste management-based energy production method and more traditional renewable energy sources like hydroelectric and wind power.

CO2-e Emissions (kg)	United Kingdom	Spain	Turkey
WtE Total	5,870	7,416	5,243
H&W	4,689	4,689	4,689
H&W vs WtE (Reduction)	- 20%	- 37%	- 11%

Table 4.8: Emissions: WTE vs H&W

Figure 4.4 includes three different routes for WTE combined with transport and landfill considerations (WTE+Transportation-Landfill) for the United Kingdom, Spain, and Turkey, compared to use of Oil or H&W. In this setup, the United Kingdom shows emissions of 5,870 kg of CO2, represented by a dark blue bar. Spain follows with a higher emission value of 7,416 kg of CO2, shown in orange, while Turkey has the lowest among them at 5,243 kg of CO2, depicted in gray. Additionally, the figure includes an alternative of H&W energy, which is consistent across all countries with emissions recorded at 4,689 kg of CO2, illustrated by a yellow bar. The strong contrast comes with the Oil alternative, where emissions skyrocket to 43,000 kg of CO2, marked by a light blue bar.

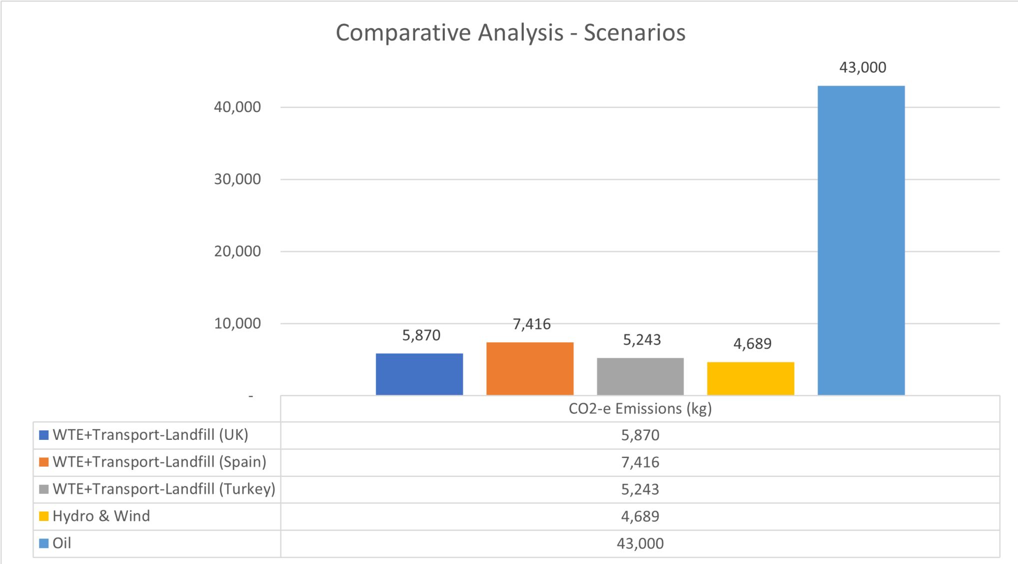

Figure 4.4: Comparative Analysis of CO2-e Emissions Across Energy Alternatives and Countries

4.8 Fuel Price Analysis

This section presents a direct examination of the weekly prices for diesel and HVO fuels by synthesizing data that was retrieved from an online database that is maintained by Shell Sweden. The data covers the period from January 2023 to the March 2024. Figure 4.5 shows the visual representation of the prices and the price gap between the two fuels is displayed in Figure 4.6.

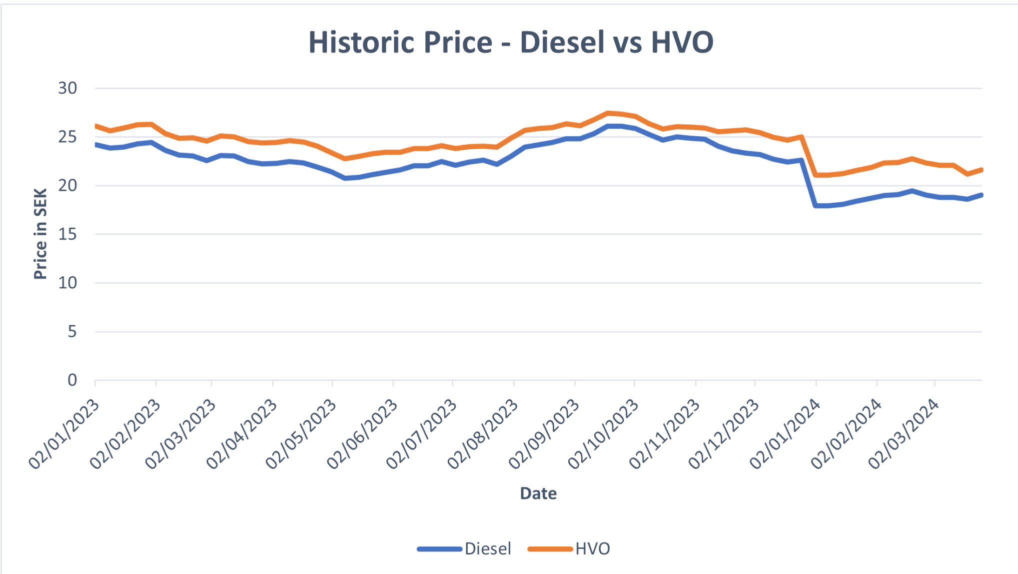

Figure 4.5: Comparison of Diesel prices (in blue) and HVO (in orange) over time, from January 2023 to March 2024, showing similar trends and prices in Swedish Krona (SEK).

The data shows a higher cost for HVO over standard diesel utilized by trucks which can be presented historically as in the Figure 4.5. The difference between these values oscillate 4% and 18%.

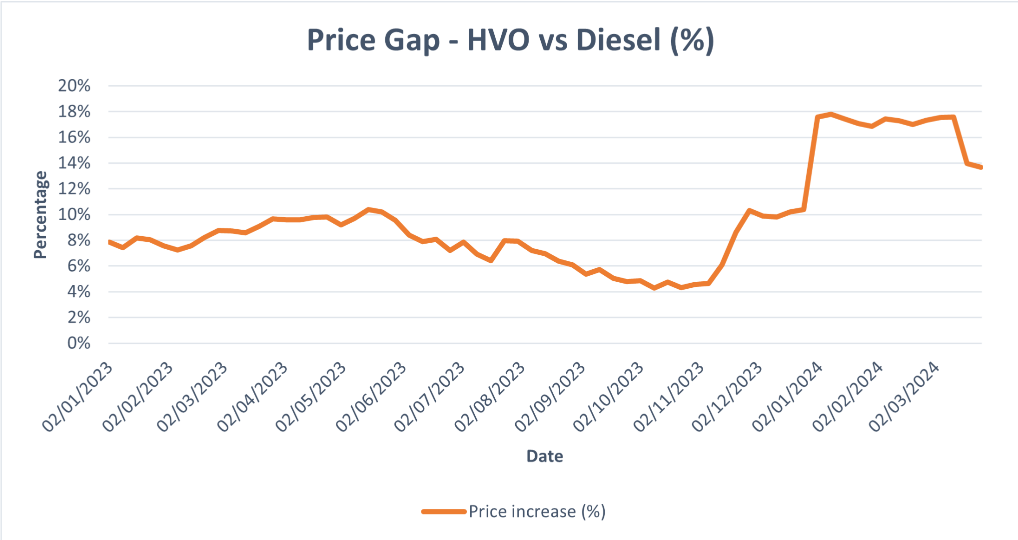

Figure 4.6: Illustration of percentage price gap between HVO and Diesel from January 2023 to March 2024

5

Discussion

The goal of this chapter is to give information that supports a critical evaluation of whether it is more beneficial to continue landfilling or to opt for transporting waste to WTE plants. This approach provides the readers with a clear understanding of the emissions generated by long-distance waste transportation, offering both qualitative insights and quantitative evidence.

5.1 Benefits and Challenges

This section explores the advantages and disadvantages concerning emissions associated with transporting waste to WTE incineration plants and landfilling.

5.1.1 Waste to energy

WTE plants have multiple advantages to be taken in consideration, such as generating revenue through two primary channels: charging gate fees for accepting waste and selling the electricity produced from this waste (Lim et al., 2019). These facilities not only dispose of waste but also convert it into useful energy, thereby creating a financial incentive to process waste, according to the findings it is estimated that the heat produced meets the yearly energy requirements of roughly 208,119 residential households every year. In addition to energy production, WTE plants utilize advanced technology to recover valuable materials from the waste processing cycle (Jofra Sora, 2013). For instance, metals can be extracted from incineration bottom ash and be recycled, adding another layer of resource efficiency to the process (Šyc et al., 2020).

Efficiency in managing emissions is another advantage of WTE facilities. They have shown significant effectiveness in controlling dioxin emissions, a group of highly toxic chemical compounds that can cause environmental pollution (Kalair et al., 2021). This capability helps reduce the potential harm to surrounding ecosystems and human health. Furthermore, a significant portion of the CO2-e emissions from WTE plants is biogenic, originating from organic materials (Astrup et al., 2009). This makes them comparatively more sustainable than emissions from fossil fuels, that generate almost 7 times more as stated in the empirical findings, as showed in Table 4.7.

Based on the routes defined in the empirical findings, it is possible to identify that, when considering electricity generation from WTE processes in the United Kingdom, Spain, and Turkey, H&W emits lower amounts of CO2-e compared to WTE, as shown in Table 4.8. This does not suggest that WTE is deficient; however, it may not always represent the most advantageous option. The findings extend the previous results, WTE also shows significantly reduced emissions compared to the traditional fossil fuel energy source. Although not as low as H&W, WTE stands out as a viable alternative that offers a considerable reduction in emissions.

A strong argument in favor of WTE processes is that they help reduce the amount of waste destined for landfills. However, it's important to consider more than just CO2-e emissions when evaluating their impact. Landfilling increases the risk of water contamination and the environmental cost of shipping waste to non-OECD countries might outweigh its benefits (Hunter, 2018; Leavitt, 2023; Organisation for Economic Co-operation and Development, n.d.; Sinha, 2019). Also, it's important to note that one primary reason H&W outperform WTE is due to the transportation involved, since it contributes between 27% to 49% of the emissions, see Table 4.6, according to the empirical findings.

On the other side, there are not only advantages but also some disadvantages. WTE plants face high operating costs (Nicastro, 2017) that stem from the intricate preparation of waste for energy conversion. This preparation includes sorting and processing waste, which are necessary steps to ensure that only appropriate waste materials are incinerated (Leavitt, 2023). Additionally, setting up a WTE plant involves significant initial capital investment, and they have usually overcapacity (Shapiro-Bengtsen et al., 2020). The infrastructure needed for these facilities is complex, including advanced technology for waste incineration and systems for energy generation. Such capital requirements are a substantial entry barrier and limits expansion in the industry. Moreover, incineration tends to be more expensive than generating energy (Kumi & Shah, 2019) from other sources like natural gas (US - Department of Energy, 2019), solar, or wind (Lazard, 2020a, 2020b). The higher cost of WTE can make it a less attractive option in economic terms, especially when compared to these increasingly cost-effective renewable energy sources.

Despite technological advancements, the environmental impact of WTE plants remains a concern. The incineration process, while efficient at reducing waste volume, can emit pollutants such as dioxins (Fundació ENT, 2015; Sharma et al., 2013), according to the e empirical findings this amount results in 441kg of CO2-e emissions per tonne of waste processed. These emissions have important health and environmental impacts (Karak, 2012), raising concerns about the long-term sustainability of incineration-based waste management. Also, incineration can undermine conservation efforts as it destroys materials that could otherwise be recycled or composted. Recycling and composting not only conserve resources but also provide materials a second life, making them more sustainable options compared to incineration (Giacomazzi, 2021; Muznik, 2018).

5.1.2 Landfilling

Energy recovery at landfill sites involves optimizing energy production through the capture and combustion of landfill gas, a natural byproduct of waste decomposition (United States Environmental Protection Agency, 2024b). This process converts waste into electricity, which is then sold back to the power grid, generating additional revenue for the landfill (National Energy Technology Laboratory, n.d.-a). Additionally, it is considered one of the most cost-effective methods for managing waste from a short-term perspective.

Eventually, many drawbacks are needed to be taken in consideration. The environmental impact of landfilling is considerable, as it can lead to soil and water contamination through the creation of leachate—a liquid that can leach toxic substances into the environment (Leavitt, 2023). Landfills also contribute to air pollution through the emission of methane and other gases, and can cause eutrophication, which increases the concentration of nutrients in bodies of water, adversely affecting water quality and aquatic life (United Nations Environment Programme, 2020). Based on the data and emission factors from the empirical findings, conventional landfilling emits about 300 kg of CO2-e per tonne of waste. Calculating the total emissions for 27 tonnes using this factor results in approximately 8,100 kg of CO2-e emissions, see Table 4.6.

Landfilling also incurs significant opportunity costs (United States Environmental Protection Agency, 2014). By dedicating large parcels of land to waste disposal, valuable land that could be used for agriculture, development, or recreational purposes is lost. Additionally, landfilling foregoes the potential benefits of alternative waste management strategies, such as recycling, composting, or WTE methods, which can offer economic, environmental, and social advantages by recovering resources and generating energy from waste. Furthermore, the post-closure costs of a landfill are significant and long-term (Duffy, 2011). After a landfill has been closed, ongoing management is required to handle issues such as leachate and landfill gas, as well as to monitor groundwater and maintain the structural integrity of the closed site (Kremen, 2023; United States Environmental Protection Agency, 2024b). These activities involve continuous financial investment and monitoring to mitigate environmental risks, spanning several decades and representing a substantial financial commitment to ensure safety and compliance with environmental regulations (United States Environmental Protection Agency, 2024b).

The social impact of landfills on local communities can also be profound. The presence of a landfill can degrade the quality of life for nearby residents through noise, unpleasant odors, and potentially lower property values due to the proximity to waste disposal sites (Vasarhelyi, 2024), which could be reduced or prevented by the implementation of more WTE facilities. These factors can lead to community dissatisfaction and opposition to landfill sites. Also, in non-OECD countries, where regulatory frameworks may be less stringent and enforcement more lax, the negative impacts can be even more pronounced (García-Galán et al., 2013; Organisation for Economic Co-operation and Development, n.d.; Sinha, 2019). Communities in these regions often face greater challenges in terms of environmental degradation and health risks associated with poorly managed landfill sites (Hunter, 2018).

5.1.3 Transportation

Considering transportation, and that all the loads will be FTL delivery method optimizes the utilization of capacity within the transportation sector. By ensuring that trailers are fully utilized, this method effectively reduces the number of trips required for waste transportation (Eisted et al., 2009). Consequently, this approach leads to a decrease in fuel consumption and minimizes GHG emissions, contributing to more environmentally friendly logistics practices.

On the other hand, transportation of waste significantly impacts the environment, primarily through the emissions of greenhouse gases, which pose a major environmental concern as mentioned by Astrup et al. (2009). These emissions vary based on the mode of transportation, whether by road, train, or sea, as showed in empirical findings, Table 4.1, Table 4.2, and Table 4.3. Each method contributes differently to the overall carbon footprint, influencing the strategic decisions made in waste management logistics.

In terms of operational and maintenance costs, transporting waste incurs high expenses (Mesjasz-Lech & Michelberger, 2019). These costs encompass fuel, vehicle maintenance, and labor, all of which are influenced by the type of fuel used and the operating environment of the vehicles (Rout et al., 2022; Sheykin, 2023). Efficient management and maintenance are crucial to controlling these costs and ensuring the sustainability of transportation operations. Additionally, regulatory and compliance costs play a significant role in the economics of waste transportation, especially when crossing international borders (Council of the European Union, 2021). Adhering to stringent environmental standards and handling requirements for hazardous materials involves legal and administrative expenses. Compliance is essential not only for legal operations but also for minimizing the environmental impact of transportation activities, adding another layer of complexity to the logistics of waste management (Secretariat of the Basel Convention, 2019).

5.1.3.1 HVO

HVO contributes to reduced emissions, significantly cutting down greenhouse gas emissions up to 92.5% compared to conventional diesel, as presented in the empirical findings, which surpasses the results of Easter et al. (2022) claiming a range from 30% to 80%. This substantial reduction aligns with international goals for decarbonization, marking HVO as a favorable alternative for a greener future (Easter et al., 2022). As a biogenic fuel, HVO is derived from renewable biomass sources, which brings notable environmental benefits (Klinghoffer et al., 2013). It plays a role in enhancing energy security by diversifying the range of fuel sources and helps in diminishing overall carbon footprints, an essential step towards combating climate change.

In terms of ecological advantages, HVO offers a healthier and more environmentally conscious alternative, with lower levels of hazardous emissions like nitrous oxides and particulates than those found in fossil diesel (Dimitriadis et al., 2018; Westphal et al., 2013). This reduction in pollutants translates to better air quality and contributes to the overall well-being of ecosystems and human health.

Moreover, HVO supports the principles of a circular economy through its production process, which involves residues, vegetable oils, and waste fats (Da Silva et al., 2023). This not only promotes the utilization of waste materials but also aids in reducing the environmental impact associated with waste, demonstrating HVO's compatibility with sustainable waste management and resource conservation practices.

According to the empirical findings, specifically into the analyzed routes, transportation impacts account for 27% to 49% of the emissions. Thus, using a more sustainable mode of transportation is fundamental to reducing emissions. For the leg from Istanbul to Stockholm, the distance by truck totals 1,718 kilometers (1,232 km + 486 km), resulting in emissions of 2,252.11 kg of CO2-e using traditional fuel, compared to only 204.16 kg of CO2-e emissions when using HVO.

But it's also true that HVO comes with a higher price tag than conventional diesel, ranging from 8% to 17% price increase, posing an economic hurdle that can impact its broader market acceptance, according to the empirical findings. The cost disparity means that despite, as seen in Figure 4.6 HVO's environmental advantages, its financial feasibility is a key factor that could limit its widespread use. Considering the average distance driven, the difference in prices represent an increase of 2.2% of the overall costs for the transportation, hence reducing the already narrow profit margins. Economic considerations play a crucial role in the adoption of HVO. Its viability as a substitute for traditional fuels is largely dependent on the economics of production and the market demand for cleaner alternatives. Market dynamics, such as the availability of raw materials and other economic factors, can greatly influence the adoption rate of HVO. This dependency on economic variables highlights the need for strategic planning and market analysis to ensure the successful integration of HVO into the energy mix.

The environmental benefits and overall performance of HVO are intrinsically linked to the type of feedstock used in its production (Di Gruttola & Borello, 2021). The feedstock mix is important as it directly influences the sustainability credentials of HVO (Da Silva et al., 2023). As stated from the empirical findings, variations in feedstock quality and source can lead to fluctuations in the eco-friendly profile of HVO, which in turn affects its suitability as an alternative fuel.

5.2 Economic Viability and Cost-Benefit Analysis

The economic assessment of waste management strategies, specifically WTE and landfilling, reveals a balance of costs and revenues that significantly influence their viability. WTE facilities incur high initial capital and operational costs due to the sophisticated technology required for converting waste into energy (Nicastro, 2017). These costs are further compounded by regulatory expenses needed to ensure environmental compliance. Despite these financial burdens, WTE facilities can generate substantial revenue through gate fees and the sale of electricity produced from waste, which helps mitigate some of the financial strain Lim et al. (2019).

In comparison, landfilling presents a less costly option upfront but entails significant long-term expenses related to environmental monitoring and maintenance to prevent pollution (Duffy, 2011; Kremen, 2023; United States Geological Survey, n.d.). Landfill operations also generate revenue, although to a lower extent, primarily through the sale of biogas produced from organic waste decomposition. However, the revenue streams from landfilling are not as robust or reliable as those from WTE facilities (National Energy Technology Laboratory, n.d.-b).

Transportation and logistics costs also play a crucial role in the overall economic framework of waste management (Mesjasz-Lech & Michelberger, 2019). These costs include expenses related to fuel, vehicle maintenance, and labor, which are necessary for transporting waste to either WTE facilities or landfills (Rout et al., 2022). The adoption of alternative fuels like HVO in transport operations introduces additional costs but can potentially reduce environmental impact, aligning with regulatory demands for cleaner operations (Zeman et al., 2019).

The choice between WTE and landfilling, therefore, hinges on multiple factors including local environmental priorities, availability of technology, and infrastructure, as well as regulatory frameworks that can tip the scales in favor of one method over the other based on economic and environmental considerations. As such, waste management strategies are evaluated not just on their immediate financial outcomes but also on their long-term implications for sustainability and compliance with environmental standards.

Figure 5.1 features a detailed heatmap that breaks down the specific categories of costs and revenues linked to landfilling and WTE operations. This visualization aids in analyzing the financial dynamics of these waste management strategies, highlighting which aspects are more costly or profitable. It serves as an effective tool for comparing the economic viability of landfilling versus WTE, helping the actors of the industry to make informed decisions based on the financial impact of each approach. In this figure the measuring scale goes from 1 to 10, indicating the intensity within the category.

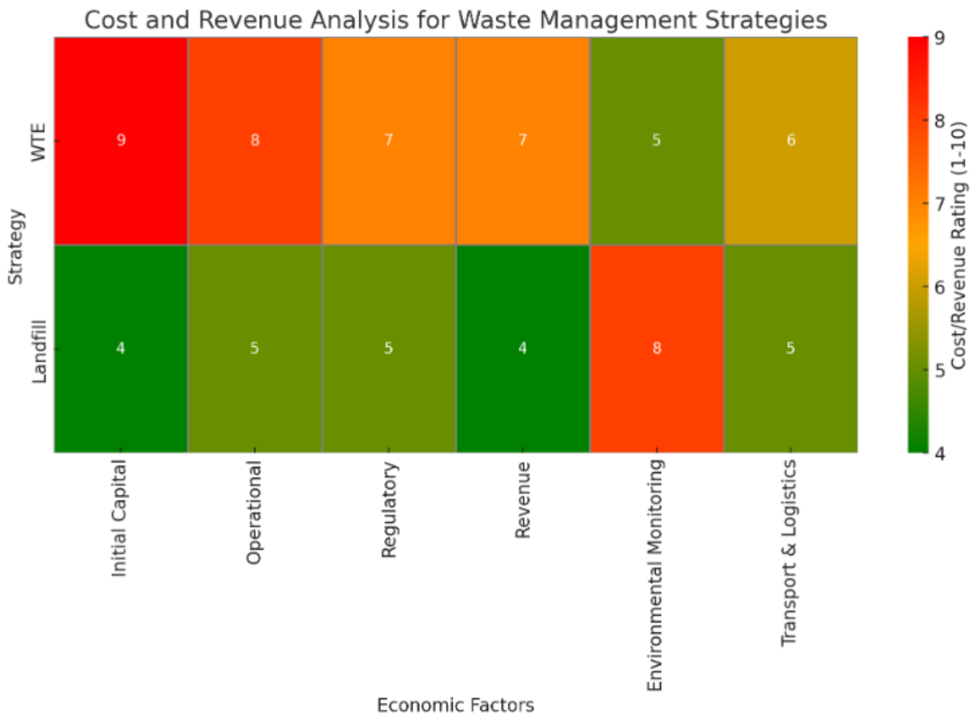

Figure 5.1: Economic Impact Analysis of Waste Management Strategies: WTE vs. Landfill

6
Conclusion

This study aimed to investigate the economic and environmental effects of waste transportation for WTE in contrast to other energy sources. This was accomplished by using extensive techniques for gathering data, such as conducting stakeholder interviews and analyzing corporate records, ERP systems, and internet databases. The three main routes from London, Madrid, and Istanbul to Stockholm were the focus of the study in order to evaluate the carbon emissions and the economic feasibility of WTE in comparison to H&W and Oil for energy production. The use of a triangulated research approach made the assessment of the financial and environmental effects of WTE transportation reliable and strong. Finally, the thesis underscores the importance of balancing economic viability with environmental sustainability.

6.1 Main Findings

According to the study, WTE methods emit substantially less CO2-e than conventional fossil fuels. This is consistent with the anticipated environmental advantages of energy recovery techniques. Nonetheless, compared to renewable energy sources like H&W, WTE emits more. This suggests that although WTE is a more environmentally friendly alternative to fossil fuels, it still falls short of the most sustainable energy sources.

One major factor contributing to overall emissions was found to be the transportation of waste to WTE facilities. Transportation emissions represent between 27% to 49% of the total in the WTE process, depending on the route. This emphasizes how important it is to take transportation logistics into account when assessing WTE's environmental impact. Significant reductions in emissions are achieved by shortening the distance waste travels and streamlining routes, and also using HVO as a substitute fuel results in a 92.5% reduction in emissions related to the transportation of waste.

Lastly, the economic assessment of waste management strategies shows that WTE facilities, despite high initial costs for technology and regulatory compliance, generate substantial revenue from gate fees and electricity sales. In contrast, landfilling has lower upfront costs but incurs significant long-term environmental monitoring and maintenance expenses. Transportation and logistics costs, including fuel, maintenance, and labor, are critical, and while alternative fuels like HVO add costs, they reduce environmental impact.

6.2 Implications for Research

This section addresses to the key implications for research discussed between WTE plants and landfilling. WTE supports energy production and a circular economy but faces many different challenges. WTE emits significantly less CO2-e compared to fossil fuels, though it still produces more emissions than renewable energy sources like hydro and wind. Transportation emissions are a significant factor and also that HVO can reduce these emissions by up to 92.5%, though its widespread adoption is limited by higher costs and availability issues.

While landfilling offers short-term cost advantages, there are long-term environmental costs and monitoring requirements to prevent soil contamination. Moreover landfill taxes in Europe are on the rise, potentially making landfilling more costly in the future compared to alternative waste management methods.

Landfilling discourages waste differentiation and recycling and often results in waste being shipped to non-OECD countries where it may not be treated properly, thus exporting environmental problems. In contrast, WTE plants convert waste into energy. In 2022, Stockholm WTE company's initiatives were projected to transform significant amounts of business and municipal residual waste into approximately 2,230 GWh of energy, enough to power roughly 42.67% of Stockholm's households. This not only reduces dependency on oil but also supports a circular economy.

However, WTE plants present drawbacks. Transporting waste to these plants increases pollution due to vehicle emissions. Alternative fuels like HVO, which can reduce emissions by up to 92.5% compared to diesel, though it remains a limited resource and its widespread adoption is hindered by cost differences and infrastructure needs. HVO also offers the benefit of being usable in existing engines without modifications, potentially extending vehicle lifespan.

Despite concerns that WTE may negatively impact recycling rates, it can actually facilitate the recovery and reuse of materials with different melting points, further contributing to resource sustainability. While WTE does produce hazardous pollutants, modern filtration technologies can mitigate these emissions. Building new WTE facilities is expensive, as exemplified by the Amager Bakke incinerator in Copenhagen, which also faces challenges with slow payback times due to underutilization. Increasing plant usage could, therefore, enhance profitability and justify the initial outlay. In summary, while WTE presents several challenges, these can be addressed, making it a viable alternative to landfilling.

6.3 Implications for Practitioners

According to this research study, logistics companies can increase their revenue and operations by supporting environmentally conscious alternatives such as WTE, and use of alternative fuels. They may improve their market appeal through effective environmental marketing and help create a more sustainable market by incorporating these solutions. By supporting WTE projects, businesses may enhance their brand image and establish themselves as major participants in sustainability. They can also draw in environmentally concerned stakeholders and customers.

Logistics companies have an important role in optimizing waste transportation to WTE facilities. Given that transportation emissions represent a significant portion of the total WTE process emissions (between 27% to 49%), optimizing logistics operations is relevant. Utilizing alternative fuels such as HVO can reduce these emissions by up to 92.5%, despite higher costs associated with HVO. Logistics companies should also prioritize short-distance routes and efficient route planning to minimize carbon footprints. Partnerships with WTE facilities across Europe should be explored to find the most efficient and sustainable logistics solutions.

In the WTE supply chain, decreasing transportation emissions relies on the production and availability of HVO. The primary objective for HVO manufacturers should be to make this alternative fuel more widely available and more affordable to consumers. Investing in the technique of transforming different feedstocks, such as residual fats and oils, into HVO could enhance sustainability and promote a circular economy. Manufacturers of HVO need to work together with logistics firms and municipalities to promote the advantages of HVO and encourage its use in the waste transportation industry. Understanding that the current supply is not capable of handle the entire demand in the case of a sudden transition of most of the actors in the industry, implies the requirement of expanding the production.

Also, incineration facilities are needed to be taken in consideration since they are converting waste into energy and focusing on maximizing efficiency and minimizing emissions. Investments in advanced technologies for emissions control and material recovery from incineration bottom ash can facilitate resource efficiency. Additionally, WTE facilities should work even more closely with logistics companies to optimize waste transportation routes and reduce overall emissions.

Municipalities, who are in charge of coordinating waste collection and transportation inside their borders, are important stakeholders in the WTE process. Municipalities can lower their dependency on landfills, lessen their local environmental effect, and help produce sustainable energy by promoting WTE initiatives. Local governments need to encourage the transportation of waste inside their borders using alternative fuels. Promoting public-private partnerships may help make investments in the technology and infrastructure that are required, which will improve the WTE supply chain's sustainability and efficiency even further.

Countries supplying waste for energy conversion need to consider the environmental and economic benefits of WTE compared to landfilling. By exporting waste to WTE facilities, countries can reduce their landfill usage, decrease long-term environmental monitoring costs, and contribute to global sustainability goals, rather than exporting the waste to non-OECD countries.

6.4 Limitations and Future Research

In order to give a more thorough assessment of WTE's advantages and disadvantages, further research should enhance the comparison of WTE with other energy sources. Furthermore, obtaining more precise and comprehensive economic data is important, as the existing data restrictions prevent an evaluation of the viability of WTE and the transportation associated with it.

In order to provide an accurate overview, future research should include specific operational data from different waste management process stakeholders. Future research should investigate other locations, countries, and companies, taking into consideration the influence of changing regulations to examine the adaptability of WTE techniques in multiple circumstances, as the conclusions of this study are particular to players like Stockholm WTE company and ECC.

Future research should also take into account various fuels and forms of transportation. To find out how alternative fuels like biofuels, BEV, and hydrogen fuel cells could affect waste logistics' carbon footprint, an evaluation of these fuels needs to be done. Furthermore, contrasting various forms of transportation, such road, rail, and sea, may show what the best way to optimize logistics is, for both financial and environmental advantages.

It is important to obtain first-hand emission data from the sources that are producing the emissions rather than depending solely on benchmark studies. With this direct method to data collecting, information becomes more accurate and current, reflecting the most recent developments in technology. Since technology is evolving so quickly, it becomes especially important to regularly update the data and methods employed in these kinds of research.

Because this study is based on European standards, additional research conducted in other locations may provide different findings. Technological developments, regulatory contexts, and geographical differences in waste management techniques should all be taken into account in future studies. For example, disparities in infrastructure, economic situations, and environmental legislation may cause waste management techniques and WTE feasibility to differ dramatically between industrialized and developing countries.

Lastly, a more thorough grasp of the economic and environmental effects of WTE as well as its likely role in globally sustainable waste management techniques may be accomplished by addressing these deficiencies and broadening the focus of future study.

Bibliography

Abdel-Shafy, H. I., & Mansour, M. S. M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum/-Egyptian Journal of Petroleum*, *27*(4), 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Anderson, E., Addy, M., Ma, H., Chen, P., & Ruan, R. (2016). Economic screening of renewable energy technologies: Incineration, anaerobic digestion, and biodiesel as applied to waste water scum. *Bioresource Technology*, *222*, 202–209. https://doi.org/10.1016/j.biortech.2016.09.076

Andreae, H. (2023, February 10). *Hvo renewable diesel: Is this the miracle fuel we've all been waiting for?* https://www.mby.com/features/hvo-renewable-diesel-miracle-fuel-124733

Asif, M. (2009). *Sustainability of timber, wood and bamboo in construction: Woodhead publishing series in civil and structural engineering* (J. Khatib, Ed.). Woodhead Publishing. https://doi.org/10.1533/9781845695842.31

Assamoi, B., & Lawryshyn, Y. (2012). The environmental comparison of landfilling vs. incineration of msw accounting for waste diversion. *Waste Management*, *32*(5), 1019–1030. https://doi.org/10.1016/j.wasman.2011.10.023

Astrup, T. F., Møller, J. S., & Fruergaard, T. (2009). Incineration and co-combustion of waste: Accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, *27*(8), 789–799. https://doi.org/10.1177/0734242x09343774

Avfall Sverige. (2022, September 1). *Treatment methods*. Retrieved February 27, 2024, from https://www.avfallsverige.se/in-english/swedish-waste-management/treatment-methods/

Azis, M. M., Kristanto, J., & Purnomo, C. W. (2021). A techno-economic evaluation of municipal solid waste (msw) conversion to energy in indonesia. *Sustainability*, *13*(13), 7232. https://doi.org/10.3390/su13137232

Banihashemi, T. A., Fei, J., & Chen, S. (2019). Exploring the relationship between reverse logistics and sustainability performance. *Modern supply chain research and applications*, *1*(1), 2–27. https://doi.org/10.1108/mscra-03-2019-0009

Beckley, D. K., & Logan, W. B. (1948). *The retail salesperson at work*. McGraw-Hill.

Binns, R. (2019, November 29). *Waste not want not: These are the most wasteful countries in europe*. https://www.expertmarket.com/uk/commercial-waste/most-wasteful-countries

Biotrux. (2023, April 25). *What can we use instead of landfills: 4 alternatives, benefits, examples & challenges*. Retrieved March 15, 2024, from https://biotrux.com/what-can-we-use-instead-of-landfills/

Brennan, R. B., Healy, M. G., Morrison, L., Hynes, S., Norton, D., & Clifford, E. (2016). Management of landfill leachate: The legacy of european union directives. *Waste Management*, *55*, 355–363. https://doi.org/10.1016/j.wasman.2015.10.010

Bronić, I. K., Barešić, J., Horvatinčić, N., & Sironić, A. (2017). Determination of biogenic component in liquid fuels by the 14c direct lsc method by using quenching properties of modern liquids for calibration. *Radiation physics and chemistry*, *137*, 248–253. https://doi.org/10.1016/j.radphyschem.2016.01.041

Browne, M., Dubois, A., & Hulthén, K. (2022). Transportation as a loosely coupled system: A fundamental challenge for sustainable freight transportation. *International Journal of Sustainable Transportation*, *17*(7), 804–814. https://doi.org/10.1080/15568318.2022.2103756

Brune, W. H., McFarland, P. J., Bruning, E. C., Waugh, S., MacGorman, D. R., Miller, D. O., Jenkins, J. M., Ren, X., Mao, J., & Peischl, J. (2021). Extreme oxidant amounts produced by lightning in storm clouds. *Science*, *372*(6543), 711–715. https://doi.org/10.1126/science.abg0492

CarbonCare. (2024). *Co2 emissions calculator*. Retrieved March 1, 2024, from https://www.carboncare.org/en/co2-emissions-calculator

Centre Tank Services Ltd. (2023, March 29). *Hvo: The sustainable fuel alternative and how it can benefit you*. https://www.centretank.com/news/what-is-hvo-and-how-you-can-benefit-from-switching-to-it

Cernuschi, S., Giugliano, M., Ozgen, S., & Consonni, S. (2012). Number concentration and chemical composition of ultrafine and nanoparticles from wte (waste to energy) plants. *Science of The Total Environment*, *420*, 319–326. https://doi.org/10.1016/j.scitotenv.2012.01.024

Chopra, S., & Meindl, P. (2015, June 1). *Supply chain management: Strategy, planning, and operation, ebook, global edition*. Pearson Higher Ed.

Council of the European Union. (2021, October 21). *Regulation - 2021/1840 - en*. Retrieved March 1, 2024, from http://data.europa.eu/eli/reg/2021/1840/oj

Creswell, J. W. (2008, July 15). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications, Incorporated.

Da Silva, M. P. D., Carreiro, S. C., Ságio, S. A., Paes, J. L., & Grajales, L. M. (2023). Transformation of solid waste into renewable energy: Perspectives for the production of 2g biofuels. *Engenharia agrícola*, *43*(spe). https://doi.org/10.1590/1809-4430-eng.agric.v43nepe20220140/2023

Del Carmen Munguía-López, A., Zavala, V. M., Santibáñez-Aguilar, J. E., & Ponce-Ortega, J. M. (2020). Optimization of municipal solid waste management using a coordinated framework. *Waste Management*, *115*, 15–24. https://doi.org/10.1016/j.wasman.2020.07.006

Demirel, Y. (2014). *Using the second law: Thermodynamic analysis: Transport and rate processes in physical, chemical and biological systems* (3rd ed.). Elsevier. https://doi.org/10.1016/B978-0-444-59557-7.00004-7

Denzin, N. K., & Lincoln, Y. S. (2017, January 5). *The sage handbook of qualitative research*. SAGE Publications.

Di Gruttola, F., & Borello, D. (2021). Analysis of the eu secondary biomass availability and conversion processes to produce advanced biofuels: Use of existing databases for assessing a metric evaluation for the 2025 perspective. *Sustainability*, *13*(14), 7882. https://doi.org/10.3390/su13147882

Dimitriadis, A., Natsios, I., Dimaratos, A., Katsaounis, D., Samaras, Z., Bezergianni, S., & Lehto, K. (2018). Evaluation of a hydrotreated vegetable oil (hvo) and effects on emissions of a passenger car diesel engine. *Frontiers in mechanical engineering*, *4*. https://doi.org/10.3389/fmech.2018.00007

Directorate General for Environment. (2022, May 24). *Waste and recycling: Commission seeks views on revision of the waste framework directive*. Retrieved April 14, 2024, from https://environment.ec.europa.eu/news/waste-and-recycling-commission-seeks-views-revision-waste-framework-directive-2022-05-24_en

Downs, A., Acevedo, R., & Humble, K. (2019, February 28). *How our trash impacts the environment*. Retrieved March 1, 2024, from https://www.earthday.org/how-our-trash-impacts-the-environment/

Duffy, D. P. (2011). Landfills, maintenance, and success. Retrieved March 15, 2024, from https://www.stormwater.com/bmps/article/13006369/landfills-maintenance-and-success

Dzioba, A., Markiewicz, M., & Gutsche, J. (2021). Analysis of modular transport systems functioning in selected european countries. *MATEC web of conferences*, *332*, 01008. https://doi.org/10.1051/matecconf/202133201008

Easter, J., Wissink, M., & Colomer, V. (2022). Impact of a commercially available low carbon renewable diesel fuel on the light-off and light-down characteristics of a diesel oxidation catalyst. *ACS omega*, *7*(35), 31367–31376. https://doi.org/10.1021/acsomega.2c03744

Eckbo, E. (Ed.). (2009). *Handbook of empirical corporate finance: Handbooks in finance*. https://doi.org/10.1016/b978-0-444-53265-7.x5001-x

Eisenhardt, K. M. (2021). What is the eisenhardt method, really? *Strategic organization*, *19*(1), 147–160. https://doi.org/10.1177/1476127020982866

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *The Academy of Management Journal*, *50*(1), 25–32. http://www.jstor.org/stable/20159839

Eisted, R., Larsen, A. W., & Christensen, T. H. (2009). Collection, transfer and transport of waste: Accounting of greenhouse gases and global warming contribution. *Waste Management & Research*, *27*(8), 738–745. https://doi.org/10.1177/0734242x09347796

Ellen Macarthur Foundation. (n.d.). *The circular economy in detail*. Retrieved March 7, 2024, from https://www.ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive

Eunomia Research & Consulting Ltd. (2024). *Costs for municipal waste management in the eu*. Retrieved April 14, 2024, from https://ec.europa.eu/environment/pdf/waste/studies/euwastemanagement_annexes.pdf

European Comission. (2023). *Reducing co2 emissions from heavy-duty vehicles*. Retrieved March 5, 2024, from https://climate.ec.europa.eu/eu-action/

transport/road-transport-reducing-co2-emissions-vehicles/reducing-co2-emissions-heavy-duty-vehicles_en

European Comission. (2024, March 1). *Waste shipments*. Retrieved March 14, 2024, from https://environment.ec.europa.eu/topics/waste-and-recycling/waste-shipments_en

European Commision. (n.d.). *What is vat?* Retrieved March 15, 2024, from https://taxation-customs.ec.europa.eu/what-vat_en#:~:text=The%20Value%20Added%20Tax%2C%20or,added%20to%20goods%20and%20services

European Commission. (n.d.). *Waste framework directive*. Retrieved April 14, 2024, from https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

European Economic and Social Committee. (2017, October 13). *Regulation (ec) no 1013/2006 of the european parliament and of the council of 14 june 2006 on shipments of waste*. Retrieved April 14, 2024, from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52017AE0719

European Environment Agency. (n.d.). *Waste-to-energy scheme*. Retrieved February 27, 2024, from https://www.eea.europa.eu/help/glossary/eea-glossary/waste-to-energy-scheme

European Environment Agency. (2022, June). *Early warning assessment related to the 2025 targets for municipal waste and packaging waste: Sweden*. Retrieved May 9, 2024, from https://www.eea.europa.eu/publications/many-eu-member-states/sweden/view

European Environment Agency. (2023a, April 26). *Reducing greenhouse gas emissions from heavy-duty vehicles in europe*. Retrieved March 14, 2024, from https://www.eea.europa.eu/publications/co2-emissions-of-new-heavy

European Environment Agency. (2023b, June 28). *National air pollutant emissions data viewer 2005-2021*. Retrieved February 27, 2024, from https://www.eea.europa.eu/data-and-maps/dashboards/necd-directive-data-viewer-7

European Environment Agency. (2024a, January 22). *Diversion of waste from landfill in europe*. Retrieved February 27, 2024, from https://www.eea.europa.eu/en/analysis/indicators/diversion-of-waste-from-landfill

European Environment Agency. (2024b, January 22). *Municipal waste landfill rates in europe by country*. Retrieved February 27, 2024, from https://www.eea.europa.eu/data-and-maps/figures/municipal-waste-landfill-rates-in-2

European Parliament. (2022, December 1). *Waste shipments: Stricter rules to protect the environment and human health*. Retrieved March 15, 2024, from https://www.europarl.europa.eu/news/en/press-room/20221128IPR58112/waste-shipments-stricter-rules-to-protect-the-environment-and-human-health

European Parliament and Council. (2021, January 11). *Regulation (ec) no 1013/2006 of the european parliament and of the council of 14 june 2006 on shipments of waste*. Retrieved March 1, 2024, from http://data.europa.eu/eli/reg/2006/1013/2021-01-11

European Parliament & Council of the European Union. (2018, June 14). *Directive (eu) 2018/851 of the european parliament and of the council*. Retrieved April 14, 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018L0851

European Parliament & Council of the European Union. (2024, February 18). *Directive 2008/98/ec of the european parliament and of the council of 19 november 2008 on waste and repealing certain directives (text with eea relevance)*. Retrieved March 8, 2024, from http://data.europa.eu/eli/dir/2008/98/2024-02-18

Fazzo, L., Minichilli, F., Santoro, M., Ceccarini, A., Della Seta, M., Bianchi, F., Comba, P., & Martuzzi, M. (2017). Hazardous waste and health impact: A systematic review of the scientific literature. *Environmental Health*, *16*(1). https://doi.org/10.1186/s12940-017-0311-8

Feng, B. (2023, April 17). *Power plant efficiency: Coal, natural gas, nuclear, and more*. Retrieved April 7, 2024, from https://www.pcienergysolutions.com/2023/04/17/power-plant-efficiency-coal-natural-gas-nuclear-and-more/#:~:text=Oil%20power%20plant%20efficiency%20rates,loss%20during%20the%20conversion%20process.

Flick, U. (2022, September 23). *An introduction to qualitative research*. SAGE.

Fundació ENT. (2015, November 19). *Air pollution from waste disposal: Not for public breath*. Retrieved March 1, 2024, from https://zerowasteeurope.eu/library/air-pollution-from-waste-disposal-not-for-public-breath/

García-Galán, M. J., Díaz-Cruz, M. S., & Barceló, D. (2013, January 1). *Fate and occurrence of phacs in the terrestrial environment*. https://doi.org/10.1016/b978-0-444-62657-8.00015-x

Giacomazzi, M. (2021, August 30). *4 reasons why recycling is better than incineration*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2017/09/4-reasons-why-recycling-is-better-than-incineration/

Gomez, E., Yan, B., Kattel, S., & Chen, J. G. (2019). Carbon dioxide reduction in tandem with light-alkane dehydrogenation. *Nature Reviews Chemistry*, *3*(11), 638–649. https://doi.org/10.1038/s41570-019-0128-9

Greenea. (2016, July 27). *Is hvo the holy grail of the world biodiesel market?* Retrieved March 5, 2024, from https://www.greenea.com/publication/is-hvo-the-holy-grail-of-the-world-biodiesel-market/

Hawks, K. (2006). What is reverse logistics? (1), 12–13. Retrieved February 23, 2024, from https://rla.org/media/magazine/view?id=7

Hennink, M., Hutter, I., & Bailey, A. (2020, January 9). *Qualitative research methods*. SAGE.

Hummel, T. (2023, November 17). *Eu reaches deal to stop sending waste to countries that can't process it* (M. Potter, Ed.). Retrieved February 27, 2024, from https://www.reuters.com/business/environment/eu-reaches-deal-stop-sending-waste-countries-that-cant-process-it-2023-11-17/

Hunter, N. D. (2018). *The law of emergencies: Public health and disaster management* (2nd ed.). Elsevier eBooks. https://doi.org/10.1016/b978-0-12-804275-5.00014-0

Inbound Logistics. (2023, February 23). *Logistics optimization: Importance, process, and optimization*. Retrieved March 7, 2024, from https://www.inboundlogistics.com/articles/logistics-optimization/

International Energy Agency. (2017, July). *The future of trucks: Implications for energy and the environment* (2nd). OECD/IEA. Retrieved May 14, 2024, from https://www.iea.org/reports/the-future-of-trucks

International Energy Agency. (2018, September 22). *Key world energy statistics 2018*. https://doi.org/10.1787/key_energ_stat-2018-en

Izadi, A., Nabipour, M., & Titidezh, O. (2020). Cost models and cost factors of road freight transportation: A literature review and model structure. *Fuzzy Information and Engineering*, 1–22. https://doi.org/10.1080/16168658.2019.1706960

Jacobson, M. (2020, April 6). *5 ways to reduce transportation costs*. Retrieved March 13, 2024, from https://www.ascm.org/ascm-insights/5-ways-to-reduce-transportation-costs/

Jaynes, C. H. (2023). Eu agrees to stop plastic waste exports to non-oecd nations unable to process it. Retrieved March 15, 2024, from https://www.ecowatch.com/plastic-waste-exports-european-union.html

Jenkins, A. (2021, January 14). *A guide to reverse logistics: How it works, types and strategies*. Retrieved March 5, 2024, from https://www.netsuite.com/portal/resource/articles/inventory-management/reverse-logistics.shtml

Jofra Sora, M. (2013, January 7). *Incineration overcapacity and waste shipping in europe: The end of the proximity principle?* Retrieved May 9, 2024, from https://www.no-burn.org/wp-content/uploads/Overcapacity_report_2013.pdf

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher*, *33*(7), 14–26. https://doi.org/10.3102/0013189x033007014

Julio, A. A. V., Milessi, T. S., Maya, D. M. Y., Lora, E. E. S., & Palácio, J. C. E. (2022). Assessment of the sustainability and economic potential of hydrotreated vegetable oils to complement diesel and biodiesel blends in brazil. *Biofuels, bioproducts& biorefining*, *17*(2), 312–323. https://doi.org/10.1002/bbb.2378

Kalair, A. R., Seyedmahmoudian, M., Stojcevski, A., Abas, N., & Khan, N. (2021). Waste to energy conversion for a sustainable future. *Heliyon*, *7*(10), e08155. https://doi.org/10.1016/j.heliyon.2021.e08155

Karak, N. (Ed.). (2012). *Biodegradable polymers*. Woodhead Publishing. https://doi.org/10.1533/9780857097149.31

Kim, J., & Jeong, S. (2017). Economic and environmental cost analysis of incineration and recovery alternatives for flammable industrial waste: The case of south korea. *Sustainability*, *9*(9), 1638. https://doi.org/10.3390/su9091638

Klinghoffer, N., Themelis, N., & Castaldi, M. J. (2013). *Waste to energy (wte): An introduction*. Woodhead Publishing. https://doi.org/10.1533/9780857096364.1.3

Korbut, M., Malovanyy, M., Boyko, R., & Masikevych, A. (2023). Determination of the sanitary protection zone of municipal waste landfill based on evaluation of the environmental hazards: Case study of the zhytomyr territorial community, ukraine. *Heliyon*, *9*(12), e22347. https://doi.org/10.1016/j.heliyon.2023.e22347

Kremen, A. (2023, December 1). *Getting a handle on landfill leachate*. Retrieved March 15, 2024, from https://www.tetratech.com/insights/getting-a-handle-on-landfill-leachate/#:~:text=Leachate%20can%20be%20treated%20by,liquor%20produced%20during%20biological%20treatment

Kumi, E., & Shah, S. (2019, June 19). *Waste-to-energy: One solution for two problems?* Retrieved March 15, 2024, from https://energyforgrowth.org/article/waste-to-energy-one-solution-for-two-problems/

Lammgård, C., & Andersson, D. I. (2014). Environmental considerations and trade-offs in purchasing of transportation services. *Research in Transportation Business & Management*, *10*, 45–52. https://doi.org/10.1016/j.rtbm.2014.04.003

Lazard. (2020a, October 19). *Levelized cost of energy analysis — version 14.0*. Retrieved May 21, 2024, from https://www.lazard.com/research-insights/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen-2020/

Lazard. (2020b, October 19). *Levelized cost of storage analysis — version 6.0*.

Leavitt, C. (2023, November 9). *Calculating the costs of waste management*. Retrieved March 15, 2024, from https://www.waste360.com/industry-insights/calculating-the-costs-of-waste-management

Lim, W., Yuen, E., & Bhaskar, A. (2019). Waste-to-energy: Green solutions for emerging markets. Retrieved March 15, 2024, from https://kpmg.com/xx/en/home/insights/2019/10/waste-to-energy-green-solutions-for-emerging-markets.html

Maalouf, A., & Mavropoulos, A. (2022). Re-assessing global municipal solid waste generation. *Waste Management & Research*, *41*(4), 936–947. https://doi.org/10.1177/0734242x221074116

Madsen, E. L. (1995, January 1). *Impacts of agricultural practices on subsurface microbial ecology*. https://doi.org/10.1016/s0065-2113(08)60897-4

Makavou, K. (2021, May 26). *The eu is clear: Waste-to-energy incineration has no place in the sustainability agenda*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2021/05/wte-incineration-no-place-sustainability-agenda/

Maletz, R., Dornack, C., & Ziyang, L. (Eds.). (2018). *Source separation and recycling: Implementation and benefits for a circular economy*. https://doi.org/10.1007/978-3-319-69072-8

Manfredi, S., Tonini, D., Christensen, T. H., & Scharff, H. (2009). Landfilling of waste: Accounting of greenhouse gases and global warming contributions. *Waste management & research*, *27*(8), 825–836. https://doi.org/10.1177/0734242x09348529

Melero, J. A., Iglesias, J., & García, A. (2012). Biomass as renewable feedstock in standard refinery units. feasibility, opportunities and challenges. *Energy & environmental science*, *5*(6), 7393. https://doi.org/10.1039/c2ee21231e

Mesjasz-Lech, A., & Michelberger, P. (2019). Sustainable waste logistics and the development of trade in recyclable raw materials in poland and hungary. *Sustainability*, *11*(15), 4159. https://doi.org/10.3390/su11154159

Mikkonen, S. (2008). Second-generation renewable diesel offers advantages. *Hydrocarbon Processing*, *87*, 63–66. https://www.researchgate.net/publication/279894818_Second-generation_renewable_diesel_offers_advantages

Miri, S., Ghanei, J., & Brar, S. K. (2022). *Characteristic of wastewater and drinking water treatment*. Elsevier. https://doi.org/10.1016/B978-0-323-85421-4.00007-3

Mohammadi, M., Jämsä-Jounela, S., & Harjunkoski, I. (2019). Optimal planning of municipal solid waste management systems in an integrated supply chain network. *Computers & Chemical Engineering*, *123*, 155–169. https://doi.org/10.1016/j.compchemeng.2018.12.022

Muznik, S. (2017, October 31). *"deliver or pay", or how waste incineration causes recycling to slow down*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2017/10/deliver-pay-waste-incineration-causes-recycling-slow/

Muznik, S. (2018, February 27). *9 reasons why we better move away from waste-to-energy, and embrace zero waste instead*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2018/02/9-reasons-why-we-better-move-away-from-waste-to-energy-and-embrace-zero-waste-instead/#:~:text=4)%20Burning%20waste%20produces%20toxic,up%20entering%20the%20food%20chain

National Energy Technology Laboratory. (n.d.-a). *5.1. gasification introduction*. Retrieved March 15, 2024, from https://www.netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/intro-to-gasification

National Energy Technology Laboratory. (n.d.-b). *6.2.6. water gas shift & hydrogen production*. Retrieved March 15, 2024, from https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/water-gas-shift

National Energy Technology Laboratory. (n.d.-c). *9.1. carbon dioxide capture & gasification*. Retrieved March 15, 2024, from https://www.netl.doe.gov/research/carbon-management/energy-systems/gasification/gasifipedia/co2removal

National Energy Technology Laboratory. (n.d.-d). *9.2. commercial carbon dioxide uses: Carbon dioxide enhanced oil recovery*. Retrieved March 15, 2024, from https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/eor

Nicastro, C. (2017, October 13). *Copenhagen goes all in on incineration, and it's a costly mistake*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2017/10/copenhagen-goes-all-in-on-incineration-and-its-a-costly-mistake/

Office of Energy Efficiency and Renewable Energy. (n.d.). *Waste-to-energy*. Retrieved March 7, 2024, from https://www.energy.gov/eere/bioenergy/waste-energy

Ohio Environmental Protection Agency. (n.d.). *Maximum achievable control technology (mact) standards*. Retrieved March 15, 2024, from https://epa.ohio.gov/divisions-and-offices/air-pollution-control/guides-and-manuals/maximum-achievable-control-technology-mact-standards#:~:text=What%20is%20a%20MACT%20standard,air%20pollutant%20(HAP)%20emissions

Okumuş, F., & Kökkülünk, G. (2023). Gemi dizel motorunda azot oksitleri (nox) indirgeme yöntemlerinin incelenmesi. *Journal of Marine and Engineering Technology*, *3*(1), 34–44. https://doi.org/10.58771/joinmet.1294204

Organisation for Economic Co-operation and Development. (n.d.). *Our global reach*. Retrieved March 15, 2024, from https://www.oecd.org/about/members-and-partners/

Paolocci, N., Jackson, M. I., López, B., Miranda, K. M., Tocchetti, C. G., Wink, D. A., Hobbs, A. J., & Fukuto, J. M. (2007). The pharmacology of nitroxyl (hno) and its therapeutic potential: Not just the janus face of no11this review is dedicated to the career of prof. herbert t. nagasawa, a pioneer in the field of hno chemistry, biochemistry and pharmacology. *Pharmacology & therapeutics*, *113*(2), 442–458. https://doi.org/10.1016/j.pharmthera.2006.11.002

Patton, M. Q. (2023, February 7). *Qualitative research & evaluation methods: Integrating theory and practice*. SAGE Publications.

Persyn, D., Díaz-Lanchas, J., & Barbero, J. (2019, March 1). *Estimating road transport costs between eu regions: Jrc working papers on territorial modelling and analysis no 04/2019* (JRC114409). Retrieved February 27, 2024, from https://econpapers.repec.org/RePEc:ipt:termod:201904

Quesada, I. F. (2003). The concept of reverse logistics. a review of literature. *ResearchGate*. https://www.researchgate.net/publication/252429818_THE_CONCEPT_OF_REVERSE_LOGISTICS_A_REVIEW_OF_LITERATURE

Rahimnejad, M. (Ed.). (2023). *Biological fuel cells*. Elsevier. https://doi.org/10.1016/c2020-0-02042-6

Recupero, R. (2019, July 24). *The not-that-well hidden risks of incineration: The case of the danish norfors plant*. Retrieved March 15, 2024, from https://zerowasteeurope.eu/2019/07/the-case-of-the-danish-norfors-plant/

Rossi, S., Colicchia, C., Cozzolino, A., & Christopher, M. (2013). The logistics service providers in eco-efficiency innovation: An empirical study. *Supply Chain Management*, *18*(6), 583–603. https://doi.org/10.1108/scm-02-2012-0053

Rossman, G., & Rallis, S. F. (2017, January 1). *An introduction to qualitative research: Learning in the field*. https://doi.org/10.4135/9781071802694

Rout, C., Li, H., Dupont, V., & Wadud, Z. (2022). A comparative total cost of ownership analysis of heavy duty on-road and off-road vehicles powered by hydrogen, electricity, and diesel. *Heliyon*, *8*(12), e12417. https://doi.org/10.1016/j.heliyon.2022.e12417

Russell, L. M. (2014). *Carbonaceous particles: Source-based characterization of their formation, composition, and structures* (H. Holland & K. Turekian, Eds.; 2nd ed.). Elsevier. https://doi.org/10.1016/b978-0-08-095975-7.00415-0

Secretariat of the Basel Convention. (2019). *Basel convention on the control of transboundary movements of hazardous wastes and their disposal*. Retrieved March 14, 2024, from https://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx

Shapiro-Bengtsen, S., Andersen, F. M., Münster, M., & Zou, L. (2020). Municipal solid waste available to the chinese energy sector – provincial projections to 2050. *Waste Management*, *112*, 52–65. https://doi.org/10.1016/j.wasman.2020.05.014

Sharma, R., Sharma, M., Sharma, R., & Sharma, V. (2013). The impact of incinerators on human health and environment. *Reviews on environmental health*, *28*(1). https://doi.org/10.1515/reveh-2012-0035

Shell Sweden. (2024, March). *Listpriser shell truckdieselkort*. Retrieved March 14, 2024, from https://www.shell.se/foretagskund/listpriser/listpriser-shell-truckdieselkort.html

Sheykin, H. (2023, October 3). *Operational expenses for a waste transportation business revealed!* Retrieved March 12, 2024, from https://finmodelslab.com/blogs/operating-costs/waste-transportation-and-logistics-operating-costs

Sinha, S. (2019, January 1). *Air pollution from solid fuels* (J. Nriagu, Ed.). Elsevier eBooks. https://doi.org/10.1016/b978-0-12-409548-9.11266-7

Smith, L., & Lampkin, N. (2019). *Greener farming: Managing carbon and nitrogen cycles to reduce greenhouse gas emissions from agriculture* (T. Letcher, Ed.). Academic Press. https://doi.org/10.1016/b978-0-12-814104-5.00019-3

Son, L. H., & Louati, A. (2016). Modeling municipal solid waste collection: A generalized vehicle routing model with multiple transfer stations, gather sites and inhomogeneous vehicles in time windows. *Waste Management*, *52*, 34–49. https://doi.org/10.1016/j.wasman.2016.03.041

Stock, J. R. (1992). *Reverse logistics: White paper*. Council of Logistics Management.

Šyc, M., Simon, F., Hykš, J., Braga, R., Biganzoli, L., Costa, G., Funari, V., & Grosso, M. (2020). Metal recovery from incineration bottom ash: State-of-the-art and recent developments. *Journal of Hazardous Materials*, *393*, 122433. https://doi.org/10.1016/j.jhazmat.2020.122433

Szeto, W., & Leung, D. Y. (2022). Is hydrotreated vegetable oil a superior substitute for fossil diesel? a comprehensive review on physicochemical properties, engine performance and emissions. *Fuel*, *327*, 125065. https://doi.org/10.1016/j.fuel.2022.125065

Thabit, Q., Nassour, A., & Nelles, M. (2022). Flue gas composition and treatment potential of a waste incineration plant. *Applied sciences*, *12*(10), 5236. https://doi.org/10.3390/app12105236

Themelis, N. (2007). Thermal treatment review: Global growth of traditional and novel thermal treatment technologies. *Waste Management World*, 37–47. https://www.researchgate.net/publication/306204081_Global_growth_of_traditional_and_novel_thermal_treatment_technologies

Thunder Said Energy. (2024, March 6). *Landfill costs: By country and over time?* Retrieved March 15, 2024, from https://thundersaidenergy.com/downloads/plastic-landfill-costs-by-country/

Tukamuhabwa, B., Mutebi, H., & Kyomuhendo, R. (2021). Competitive advantage in smes: Effect of supply chain management practices, logistics capabilities and logistics integration in a developing country. *Journal of business and socio-economic development*, *3*(4), 353–371. https://doi.org/10.1108/jbsed-04-2021-0051

United Nations. (1989, March 22). *Basel convention on the control of transboundary movements of hazardous wastes and their disposal*. Retrieved March 1, 2024, from https://treaties.un.org/pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-3&chapter=27&clang=_en

United Nations Environment Programme. (n.d.). *Solid waste management*. https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management

United Nations Environment Programme. (2020, September 7). *Waste not: The heavy toll of our trash*. Retrieved March 15, 2024, from https://www.unep.org/news-and-stories/story/waste-not-heavy-toll-our-trash

United Nations Environmental Programme. (2019). *Waste to energy: Considerations for informed decision-making*. Retrieved March 7, 2024, from https://www.unep.org/ietc/resources/publication/waste-energy-considerations-informed-decision-making

United Nations Statistical Division. (1997). *Glossary of environment statistics* (Series F, No. 67). United Nations.

United States Environmental Protection Agency. (2014, June). *Economic impact analysis for the proposed new subpart to the new source performance standards*.

United States Environmental Protection Agency. (2023, November 28). *Epa's office of resource conservation and recovery (orcr)*. Retrieved February 22, 2024, from https://www.epa.gov/aboutepa/epas-office-resource-conservation-and-recovery-orcr

United States Environmental Protection Agency. (2024a, January 30). *Energy recovery from the combustion of municipal solid waste (msw)*. Retrieved March 15, 2024, from https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw

United States Environmental Protection Agency. (2024b, February 12). *Benefits of landfill gas energy projects | us epa*. Retrieved March 15, 2024, from https://www.epa.gov/lmop/benefits-landfill-gas-energy-projects

United States Environmental Protection Agency. (2024c, March 19). *Greenhouse gases equivalencies calculator - calculations and references*. Retrieved May 7, 2024, from https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

United States Geological Survey. (n.d.). *Groundwater and streamflow information program*. Retrieved March 15, 2024, from https://www.usgs.gov/programs/groundwater-and-streamflow-information-program

U.S. Department Of Energy. (2020). *Biomass to biofuels: Glossary of terms and conversion factors* (A. Dahiya, Ed.; Second Edition). Academic Press. https://doi.org/10.1016/b978-0-12-815497-7.00003-8

US - Department of Energy. (2019, December 10). *Department of energy year in review - 2019*. Retrieved March 15, 2024, from https://www.energy.gov/articles/department-energy-year-review-2019

U.S. Energy Information Administration. (2023, November 6). *Biomass explained: Waste-to-energy (municipal solid waste)*. Retrieved March 15, 2024, from https://www.eia.gov/energyexplained/biomass/waste-to-energy.php

Vallero, D. A. (2021). *Environmental system dynamics: Theory and practical applications*. Elsevier. https://doi.org/10.1016/b978-0-12-821953-9.00007-6

Vasarhelyi, K. (2024, January 17). *The hidden damage of landfills*. Retrieved March 15, 2024, from https://www.colorado.edu/ecenter/2021/04/15/hidden-damage-landfills

Vattenfall. (2024, March 28). *Annual and sustainability report 2023*. Retrieved April 30, 2024, from https://group.vattenfall.com/investors/financial-calendar/annual-and-sustainability-report-2023

Walsh, J. (2023, November 9). *Post-closure costs: Budgeting the unknown*. Retrieved March 15, 2024, from https://www.waste360.com/industry-insights/post-closure-costs-budgeting-the-unknown

Westphal, G. A., Krahl, J., Munack, A., Rosenkranz, N., Schröder, O., Schaak, J., Pabst, C., Brüning, T., & Bünger, J. (2013). Combustion of hydrotreated vegetable oil and jatropha methyl ester in a heavy duty engine: Emissions and bacterial mutagenicity. *Environmental science& technology*, *47*(11), 6038–6046. https://doi.org/10.1021/es400518d

Willoughby, J. O. (2002, January 1). *Insulation* (Snow, Ed.; 2nd ed.). Butterworth-Heinemann. https://doi.org/10.1016/b978-075064452-5/50085-7

WtERT. (n.d.). *Home*. Retrieved March 15, 2024, from https://wtert.org/

Yin, R. K. (2014). *Case study research* (5th). SAGE Publications. https://books.google.fi/books?id=Cdk5DQAAQBAJ

Zeman, P., Hönig, V., Kotek, M., Táborský, J., Obergruber, M., Mařík, J., Hartová, V., & Pechout, M. (2019). Hydrotreated vegetable oil as a fuel from waste materials. *Catalysts*, *9*(4), 337. https://doi.org/10.3390/catal9040337

Zohrabi, M. (2013). Mixed method research: Instruments, validity, reliability and reporting findings. *Theory and practice in language studies*, *3*(2). https://doi.org/10.4304/tpls.3.2.254-262

DEPARTMENT OF SOME SUBJECT OR TECHNOLOGY
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY