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Waste as a Strategic Resource: Shifting From the Burden of Disposal to Investment Opportunities in Renewable Energy"A case study of France Experience"

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Abstract

This study examines the French experience in waste management and energy recovery, by analyzing the issue of balancing recycling objectives and recovery in order to ensure the economic and environmental feasibility of waste management. It is based on the hypothesis that the economic feasibility of waste-to-energy facilities in France depends on the significance of revenues generated from energy sales, on recovery costs being lower than those of non-energy solutions, and on their ability to comply with strict environmental regulations. The study relied on both descriptive and analytical methods. The results showed that the success of the French experience is based on three pillars: financial, through a dual revenue system and tax incentives; technological, through high quality energy production; and legal, through restrict legislation. In addition, it involves the adoption of decentralized governance granting municipalities broad powers, and the implementation of continuous monitoring standards to ensure public acceptance and environmental protection.

Keywords: Waste, energy recovery, French experience

Introduction :

The world is currently facing major challenges related to waste management in light of the growing environmental awareness, as the quantities of waste produced are increasing significantly and rapidly in line with continuous population and consumption growth. These quantities increase even more as humans adopt more modern lifestyles, making the volume of generated waste a huge environmental and economic burden. On the other hand, the demand for energy is rising considerably due to the requirements of contemporary life and changing consumption patterns,

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especially with ongoing technological developments, in addition to the global energy crisis, which has intensified as a result of various crises. This has pushed to governments and organizations to search for sustainable solutions that go beyond traditional landfilling in a world increasingly marked by energy crises. In this context, the concept of waste-to-energy "WTE" has emerged as one of the strategies that achieves a "dual benefit": It reduces the volume of waste directed to landfills, while at the same time contributing to the diversification and security of energy sources.

France, with its long history of industrial innovation and its strong commitment to achieve in the European Union's objectives in the field of the circular economy, represents a leading case study that deserves in-depth analysis in the field of WTE recovery. For decades, France has invested heavily in developing advanced infrastructure to treat the tons of waste accumulated in its streets and to find solutions to the resulting environmental and health issues. On the other hand, the adoption of this technology faces significant challenges and debate, especially with regard to environmental emissions and the operating costs of WTE projects. Studying the French experience allows us to understand how to balance environmental, economic, and energy requirements, as the position of WTE recovery has shifted from being "the last solution before landfilling" to becoming a pillar of energy sovereignty and a means of financing the environmental transition, as a result of complex economic, geopolitical, and environmental pressures.

Despite France's clear success in developing a strong infrastructure for WTE recovery, which has contributed to reducing dependence on landfills and securing a sustainable source of energy, this practice raises fundamental questions about the context of the transition toward a circular economy and the goals of carbon neutrality. In light of this debate, the main research problem of this article emerges as follows:

- How can France achieve economic, environmental, and energy balances while continuously seeking to strengthen recycling objectives and ensure the sustainability of WTE recovery pathways?

This main problem gives rise to the following sub-questions:

1. What is the current French legislative and financial framework, and how does it ensure alignment between the efficiency of WTE technologies and emission reduction standards?
2. Is WTE recovery in France viewed as a competitor to recycling efforts, or is it considered a crucial complementary solution for waste treatment?
3. What is the economic feasibility of WTE plants in France?
4. What are the lessons learned from the French experience in the field of WTE recovery?

To answer these questions, we relied on the following hypotheses:

1. The success of the French experience in WTE recovery is due to the existence of an integrated and supportive legislative framework that works to ensure the efficiency of optimal technologies for energy production, provides financial support for them, and at the same time ensures compliance with the environmental obligations associated with this activity.
2. WTE recovery represents a fundamental pillar in the circular economic system in France by providing a profitable final solution to the waste problem, and reducing dependence on traditional energy sources.
3. The economic feasibility of WTE plants in France depends on the revenues generated from energy sales, as well as on their ability to face challenges, foremost among them the

environmental challenges and the fluctuations affecting the waste market, in addition to enhancing opportunities for creating new jobs in the field of waste management, and its conversion into clean energy.

This article aims to identify the role of governments in formulating a comprehensive national strategy to consolidate the foundations for the success of WTE transition, linking it to local energy needs, and highlighting the importance of local authorities in converting waste into an energy resource, by providing an economic and environmental analysis of WTE recovery model in France. This can be achieved through the following specific objectives:

1. To analyze how WTE recovery is integrated into the broader French national objectives for waste and energy management, while determining its current position within the waste management hierarchy.
2. To examine whether investment in WTE recovery constitutes an obstacle to achieving ambitious recycling targets, or whether it focuses exclusively on treating a specific type or portion of waste more efficiently than recycling, or perhaps only deals with waste that cannot be recycled.
3. To evaluate the environmental and economic performance of the sector in terms of reducing greenhouse gas emissions, managing secondary waste (in comparison with other waste treatment methods, especially landfilling), energy efficiency, and its impact on employment.
4. To provide conclusions and recommendations that can benefit other developing or developed countries seeking to adopt or revise their WTE strategies.

The topic of waste and its energy conversion has been tackled in numerous studies, which dealt with different aspects of the subject, this includes:

"Waste to Energy: Trends and Perspectives" (Lisbona, Pascual, & Pérez, 2023), examines different types of raw materials, discusses the latest technologies used in WTE processes and the expected trends for each process in the coming years. The study finds that European policies support using waste and bioenergy for heating and cooling, producing biofuels and renewable hydrogen, and generating more electricity through highly efficient combined heat and power plants, while gradual elimination of indirect changes in land-use. It also emphasizes the importance of characterizing waste before energy conversion, as sound management and classification help select the most suitable conversion methods and final energy outputs.

The study entitled "Acceptance of Waste to Energy Technology by Local Residents of Jakarta City, Indonesia to Achieve Sustainable, Clean, and Environmentally Friendly Energy" (Suryawan, et al., 2023), focused on assessing the level of public acceptance of WTE technology, which allows for efficient waste management through raising public awareness, by studying a random sample of Jakarta residents. The results showed that the total variance explained by the three factors (socio-economic, environmental impact and development) reached 72.11 %. The socio-economic aspect reflects the community's ability to recognize opportunities, the environmental impact reflects public awareness, and development refers to the technical aspects of advancing WTE conversion. The socio-economic aspect emerged as the most decisive factor for public preference and acceptance of WTE projects, with education level and potential project income identified as the key determinants for developing and implementing these projects.

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"Renewable Energy, Energy Efficiency, and Economic Complexity in the Middle East and North Africa: A Panel Data Analysis" (Taghvaee, Saboori, Soretz, Magazzino, & Tatar, 2024), studied how economic complexity and structural transformation affect energy security in the Middle East and North Africa. It focused on two indicators: energy efficiency and the shift to renewable energy. The study found that economic complexity reduces energy efficiency but supports renewable energy because it is energy-intensive yet environmentally friendly. Economic growth, in contrast, improves energy efficiency but reduces renewable energy use, as it says energy but is environmentally harmful. However, the negative effects of both are larger than their positive effects, suggesting the need to restructure economic activities and encourage the use of energy-efficient technologies to strengthen energy security and reduce reliance on fossil fuels.

"Waste to Energy Technology Selection: A Multi-criteria Optimization Approach" (AlNouss, et al., 2024). The study aimed to develop a framework to help in selecting the optimal WTE technology, by studying five types of waste available in Qatar (date pits, camel manure, municipal solid waste, food waste and sewage sludge), three technologies (pyrolysis, gasification and hydrothermal liquefaction) and evaluating them in terms of their technical, environmental and economic performance. The model showed that the choice of technology differs according to the objective and the nature of the waste. Gasification is the most suitable for achieving a higher economic return, pyrolysis for achieving the highest energy yield, and hydrothermal liquefaction is preferred in terms of environmental performance and lower associated emissions. Gasification treats different types of waste (municipal solid waste, food waste, etc.) in the best way to meet environmental and economic standards, while pyrolysis is more energy-efficient in waste treatment. Hydrothermal liquefaction is recommended only for high moisture biomass such as sludge, as it shows relatively high-energy efficiency but a lower economic return compared to pyrolysis and gasification.

As for our study, it focuses on waste as a strategic resource within the framework of finding ways to address the energy crisis and solve the issue of waste accumulation simultaneously. This is achieved by focusing on the shift from a purely environmental perspective to an investment and competitive perspective of WTE recovery and the challenges it faces, through presenting the French experience.

To achieve the research objectives, we adopted a descriptive approach to describe the phenomenon of waste and the mechanisms of its energy recovery, and to present the legal framework and French public policies related to waste management and renewable energy. We also used an analytical approach to analyze and evaluate its economic and environmental feasibility, draw conclusions and propose recommendations from it.

I. The conceptual and statistical framework of waste and its energy recovery

Effective waste management cannot form part of a sustainable vision except through accurate knowledge of the evolution of waste flows, and more importantly their composition. This makes it possible to improve management methods and supports the creation of channels for material recovery (Zokpénou, 2024, p. 364). Waste management refers to a set of consistent and systematic rules that govern the generation of waste, its collection, transport, treatment, and disposal according to specific principles. It is a complex and multi-level process that involves government policy-making as well as administrative, financial, legal and research institutions (Karungamye,

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2024, pp. 03-04). Therefore, defining and classifying waste represents a fundamental and necessary step for the success of this process.

1. The concept of waste and its classification:

The criteria used in formulating the definition of waste vary. The definition may rely on mentioning the source of the waste, its nature or types, or it may focus on the idea of abandoning or disposing of it, or on the reasons for its disposal. The definition may also be based on a single criterion or on a combination of several criteria. Thus, waste is defined by some as goods that their owner intends to discard. There are also terms such as garbage, residue, and refuse, which are used to refer to this items or remains that are no longer desired (Turlan, 2018, p. 03). The European Union defines waste broadly and comprehensively to ensure the inclusion of all materials requiring sound environmental management. Article 3(1) of the waste framework directive states that: "waste means any substance or object which the holder discards, intends to discard, or is required to discard" (JO de l'UE, 2008, p. 09). French environmental law (art. L 541- 1) defines it as "any substance or object, or more generally, any movable property, which its holder discards, intends to discard, or is obliged to discard" (Michel , p. 02). Several criteria exist for classifying waste, primarily by source (households, businesses, municipalities, agriculture). Generally, several types are distinguished: Biodegradable materials, including sludge from wastewater treatment, green waste, and ordinary or special industrial waste. According to the collection method, waste is classified into household waste, commercial and artisanal waste, and waste from small businesses, excluding waste from households following specific disposal streams (such as batteries and pharmaceuticals). Waste can also be classified according to how it is treated and the outcomes of this treatment (form and quantity of energy, nature of the products resulting from treatment) (Prévot, 2000, pp. 05-06).

2. Statistical framework of waste and its impact on environment, economy, and society:

The world generates approximately 07 to 10 bn tons of waste annually (Un-habitat, 2019, p. 02). Of this, 02 bn tons are solid waste (UNEP/ISWA, 2024, p. 09), and according to World Bank estimates, this amount could rise to 3.4 bn tons by 2050 (ONU, 2024, p. 03). Around 44 % of global waste is classified as food and green waste, 38 % as dry recyclable materials (paper, cardboard, plastic, glass, metals), and the remaining 18 % include rubber, leather, wood, and other materials (ADB, 2020, p. 01) Waste composition also varies according to income levels. High-income countries produce relatively smaller amounts of food and green waste (32 %) and larger amounts of dry recyclable waste (51 %). On the other hand, countries with middle and low incomes generate 53 % of food waste and 56 % of green waste, with the proportion of organic waste increasing as economic development levels decrease. In low-income countries, recyclable materials account for only 16 % of total waste (Kaza, Yao, Bhada- Tata, & Van Woerden, 2018, p. 07). Food waste is also a significant issue. Total food waste reached 1.05 bn tons in 2022 (FAO, 2025), with households accounting for the largest share of this waste worldwide 60 % (UNEP, 2024, p. XII), as families waste 01 bn meals daily (Cloutier, Roy, & Afif, 2024, p. 01). One third of global solid waste is not managed in an environmentally safe manner and is disposed of in open sites, why only one-fifth undergoes material recovery, and 80 % of collected wastewater is discharged into water bodies (Un-habitat, 2019, p. 02).

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Waste production reached 355 M tons between 2004 and 2010 in France (nearly + 20 %) (ADEME, 2014, p. 13). Afterward, the quantities produced showed a continuous decrease, reaching 6 % in 2014 (ADEME, 2020, p. 23). Following a period of stability at around 320 M tons between 2014 and 2016, the quantity rose to 343 M tons in 2018, before dropping again to 315 M tons in 2020, excluding agricultural residues reused on farms and those related to waste treatment. This decline was mainly due to the strong impact of covid-19 on economic activities, and consequently, on the amount of waste generated. Household waste accounted for about 80 % of household and similar waste, while the remainder consisted of waste from small businesses or administrations collected simultaneously with household waste. Hazardous waste was estimated at 11 million times, primarily produced by companies: 2.3 M tons from industry and 2.6 M tons from the construction sector. Waste collection and treatment services, as well as water and sanitation services, generated 3.6 M tons. The majority of non-hazardous waste consisted of metal waste, totaling 209 M tons (ADEME, 2023, pp. 23-24). In 2021, household and similar waste were estimated at 611 kg/inhabitant/year, of which 500 kg where household waste (ADEME, 2024, p. 12).

Poor waste management has negative effects which can be divided into three main categories:

Impacts on human life: Waste affects public health directly or indirectly, through the increase in work-related injuries resulting from handling medical waste, and through direct risks through inhaling gases emitted from the decomposition of waste, as well as microorganisms and microbes. It also needs to diseases resulting from hazardous waste containing heavy metals, such as cancer, neurological and respiratory disorders, and congenital defects (MEW, 2015, p. 222). The risk increases for people who have direct contact with waste or who live near disposal sites, as estimates indicate that 02 bn people live in areas where waste collection is absent and rely on uncontrolled and unmanaged dumps (EPA, 2021, pp. 03-09). It also leads to the death of between 400,000 and one million people annually due to diseases resulting from poor waste management (Un-habitat, 2019, p. 02).

Impacts on the environment: Industrial, scientific, and economic developments have led to the emergence of large quantities of chemical, electronic and electrical products, resulting in hazardous materials, which are highly toxic, difficult to decompose and their effects persist for long periods. There is also a risk of their leakage into food chains if they are dumped at the sea, leading to water pollution and fish death (MEW, 2015, p. 220). Between 08 and 10 M tons of plastic are dumped into the oceans every year, with 80 % of marine waste originating from land-based sources and 20 % from Marine activities (Valero, 2020). Plastic requires hundreds of years to fully decompose. For example, a baby diaper may take around 450 years to break down (OFEV, 2016, pp. 23-24). Each year, plastic leaking into the ocean kills around a 100 M marine animals (Un-habitat, 2019, p. 02). The poor control of leachate resulting from waste can lead to soil and water contamination, degradation of local ecosystems, and threats to the lives of stray and wild animals through the consumption of food residues. Black carbon also affects air quality at the regional level and the climate at the global level (EPA, 2021, p. 09). The decomposition of organic materials in waste leads to the spread of toxic gases and unpleasant odors. Waste may also cause dust emissions, the risk of fires, and the release of smoke and harmful gases from these fires (Aissa, p. 07 ‹08). It may also lead to explosion risks and global warming, as one ton of methane gas has

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an effect equivalent to 21 tons of carbon dioxide. This also means that one ton of carbon in the form of methane has a warming effect equivalent to 7 tons of carbon in the form of carbon dioxide (Prévot, 2000, p. 12). According to the intergovernmental panel on climate change, waste and wastewater account for 3 % of greenhouse gas emissions (Un-habitat, 2019, p. 02).

Impacts on the economic and social situation: Poor waste management can be very costly and results in direct and indirect costs that may constitute an obstacle to economic growth, especially with regards to property values and tourist areas linked to clean roads and beaches. Waste reduction programs can lead to savings in transport and fuel costs and have improved cost efficiency. Proper management of solid waste can also benefit public health systems by reducing respiratory and skin diseases and other health problems associated with improper waste management (EPA, 2021, p. 10). Studies related to productivity have shown that a person living in a clean environment is 30 % to 40 % more protective than one living in an unclean environment. Large accumulations of waste may also disrupt traffic and transportation. In addition, the failure to exploit the materials contained in waste leads to the loss of a large amount of energy that should be preserved and utilized (Aissa, pp. 8-9). In general, the lack of proper and adequate waste management has led to excessive pollution of air, soil, and water, which threatens public health, ecosystems, and biodiversity. It has also resulted in the accumulation of large quantities of waste in the world's oceans, especially since 90 % of urban areas are located on coasts. This pollution has significant economic impacts on tourism, fisheries, and healthcare, estimated at about 375 $/ton of solid waste (Un-habitat, 2019, p. 02). Studies indicate that the total economic damage caused by plastic in the global marine ecosystems reaches at least 13 bn$ annually. According to the United Nations report of (2018), bearing the title "State of Plastics: World Environment Day Outlook", cleaning coastlines and beaches to remove plastic waste in Europe costs around 630 M€/year (Valero, 2020).

3. **Risks of pollutants emitted from conventional power generation plants:**

More than 70 % of global emissions come from energy use (Haussman, 2022, p. 15). To this day, about 80 % of global energy demand is met through the consumption of fossil fuel resources (AlNouss, et al., 2024, p. 01). The gaseous emissions resulting from the exploration and exploitation of this fuel have caused unprecedented environmental damage. In addition, the reserves of this resource are limited and may be fully depleted in the near future due to their increasing use (Alao, Popoola, & Ayodele, 2022, p. 01). Fossil fuel emissions threaten marine ecosystems, as rising sea temperatures lead to coral bleaching and widespread coral death. About 50 % of coral cover in the Great Barrier Reef has been lost since the 1980s (StrategyHub, 2024, p. 09). There's a growing concern about the direct health effects of burning fossil fuels, especially as fast-growing economies are facing rapid deterioration in air quality and a sharp increase in respiratory diseases. "The United States Environmental Protection Agency" recently found that health damage resulting from the use of this fuel costs the local economy between 362 and 887 bn$ annually. The Health and Environment Alliance of the European Union also confirmed that emissions from coal-fired power plants cost its citizens up to 42.8 bn€/year in health costs (IRENA, 2021, p. 02). In China, the health costs of coal use reached 11.70 $/gigajoule of energy (Parry, 2014, p. 17) In addition to these impacts, there are local disasters, such as the Deepwater Horizon oil spill in the United States (IRENA, 2021, pp. 02-03). As for energy production using nuclear power, the laws regulating nuclear activities allow limited and controlled levels of radiation to leak into the surrounding environment, on the assumption that they do not affect health. However, a report by the US National Research Council Committee on the effects of low-level radiation in 2006 confirmed that there is no such thing as a "safe dose", no matter how small. Prolonged exposure to radiation leads to cancer in the long term, while intense exposure can lead to death in a short time. Radon gas that results from uranium mining is considered responsible for about half of lung cancer cases in the United States. On the other hand, nuclear power plants waste large quantities of water, which are discharged hot and loaded with sediments into nearby waterways, negatively affecting the ecosystem and water quality. They may also leave mining residues piled near uranium mines and exposed to accidents. For examples, the leaks that occurred in 1979 into the Rio Porco River, and in 1984 into the Colorado River. There may also be what is called "unintentional leakage" of radioactive materials. The US Nuclear Regulatory Commission documented 14 incidents during the period (1986- 2006). In addition, there is the Fukushima nuclear accident in Japan, where in 2016 the official estimate of the cost of addressing its consequences was about 200 bn$. The Japan Center for Economic Research believes that the cost is much higher and may reach 635 bn$ (E.I.P.R, 2019, pp. 27, 35,55).

The massive growth in electricity generation has exceeded 250 % over the last 40 years. It is expected to increase by 70 % to reach 37,000 Thw by 2030 worldwide (IRENA, 2021, p. 01), energy demand is also expected to rise by 30 %, based on a global economic growth rate of 3.4 %, and a world population of more than 09 bn people by 2040 (IEA, 2017, p. 04). The World Economic Forum estimates that the extraction and processing of raw materials alone cost more than 90 % of global biodiversity loss and water stress, and about half of the impacts of global climate change. It also points out that the efficient use of resources and business models that do not rely on resource extraction represent a large and still underexploited field for innovation and for a new model of growth (Thirlway, 2020, p. 11). In light of these facts, it becomes clear that there is a need to search for clean alternatives for energy generation, relying on renewable energy sources in order to limit global warming to 1.5° C above pre-industrial levels, which is one of the objectives of the Paris Agreement. To reach this goal, the Intergovernmental Panel on climate change of the United Nations estimated in a 2018 report that renewable energy sources should generate between 70 % and 85 % of electricity by 2050 (Norton, 2020, p. 56). With the growing need for alternative energy sources, interest has increased in the economic value of waste and the energy it contains. Many countries have developed different Technologies to convert waste into energy that can be used for several purposes such as heating and Industry, as a result, energy generated from this source has come to represent noticeable shares of countries' energy mix (Sabri, Mahmoud, & Abou, 2018, p. 18).

4. The nature of waste-to-energy recovery and the adapted technologies:

The world today is facing many problems, including climate change, resource scarcity, and energy security. As a result, the importance of energy efficiency has increased. It is considered a key means to reduce greenhouse gas emissions, preserve energy resources and enhance economic productivity, which are all essential elements for sustainability (Taghvaee, Saboori, Soretz, Magazzino, & Tatar, 2024, p. 01). Energy efficiency means using energy in the most cost-effective way to carry out a production process or provide a service, which reduces energy waste, and lowers

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the overall consumption of primary energy resources. In other words, energy efficiency practices or systems aim to use less energy when performing any activity that depends on energy, while at the same time reducing the negative environmental impacts of energy consumption (UNIDO, p. 04). Enhancing the recovery and use of energy from waste contributes not only to reducing primary energy consumption, but also to lowering pollutant emissions and achieving the related economic benefits (Zhang, Zhao, Lu, Ni, & Li, 2017). Sustainable waste management is necessary to achieve a sustainable world in which the goals of the circular economy are realized. Energy recovery processes are considered the final step after reduction, reuse, or recycling, and they contribute to providing renewable energy to populations, in addition to being a waste management system (Lisbona, Pascual, & Pérez, 2023, p. 01). By turning waste from a burden into a resource, waste valorization supports efficient use of resources, waste reduction and closed-loop systems that reduce the extraction of raw materials and environmental degradation. WTE technologies use a mix of recycled municipal solid waste and Industrial residues (Idoghor, Saah, Nwandu, Adeoba, & Egbubine, 2026, p. 13). The inability to recycle large quantities of hazardous organic materials makes it necessary to adopt WTE technologies as a more effective option to achieve a sustainable solution (Chicaiza-Ortiz, et al., 2024). The concept of energy recovery refers to the conversion of non-recyclable materials into heat, electricity and fuel through several stages known as WTE valorization (EPA, 2021, p. 18). The term valorization has two meanings: In the usual sense, it refers to a transformation that gives the product a higher value, and this has no economic justification unless the costs incurred are lower than the increase in value. According to the official sources (legislative and Regulatory texts), waste is considered valorized if it finds uses either as a material or as a source of energy (Prévot, 2000, p. 83). The choice of waste to energy technology depends on operating costs, labor skill requirements, and the source of the waste (Zhou & Zhang, 2022).

The waste to energy techniques include:

Incineration of waste: It is the most common method worldwide due to its relatively reasonable cost and ease of implementation compared to other technologies, especially since converting coal-fired power plants to WTE generation does not require new investments. The United States alone has converted 55 coal plants to biomass. In OECD countries, new incineration plants comply with strict emissions standards (Sabri, Mahmoud, & Abou, 2018, p. 19). These strict standards include measuring nitrogen oxides, heavy metals and dioxins, as well as managing toxic fly ash, bottom ash and emitted pollutants (Directorate of Environment, 2019). The recovery of combustion heat produces steam that can be used as a heat carrier or for electricity generation. The incineration of 100,000 tons of household waste provides 170 Gwh of usable heat, if all this heat is converted into electricity, it would produce 43 Gwh (Prévot, 2000, p. 11).

Anaerobic digestion: This is a biological method for treating animal waste, sewage, or household residues, producing three products: biogas, digestate liquid and organic fertilizer. The biogas consists mostly of methane and can be used in power plants or internal combustion engines to generate electricity and heat. The digestate liquid and organic fertilizer can be used to improve soil fertility (Sabri, Mahmoud, & Abou, 2018, p. 19). One ton of fermented material produces biogas with a calorific value of 700 kWh. If the combustion heat of the biogas is used directly, the usable heat equals about 2/3 of the usable heat from the combustion of that fermentable portion (Prévot,

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2000, p. 11). Anaerobic digestion has several advantages: It does not discharge liquid waste in a pollutant manner if the treated water is reused, reduces waste volume by 85 %, keeps treatment costs low (not exceeding 12 $/ton), and lowers capital and operational costs compared to aerobic treatment plants (Sabri, Mahmoud, & Abou, 2018, p. 20).

Plasma gasification: This process converts the entire treated amount of organic and inorganic waste, including environmentally hazardous waste, into gases. Its advantages include the absence of Ash (a major problem in conventional incinerators) and a higher energy yield compared to direct combustion technology (Directorate of Environment, 2019). It allows low-value fuels and residues to be transformed into synthetic gas (municipal solid waste, waste-derived fuel, non-recyclable plastics, agricultural industry residues, dried sewage sludge, and coal). The synthetic gas is used in large power plants to generate electricity and produce heat, making it attractive both economically and environmentally. It can also be converted into methanol, ammonia, synthetic gasoline or used directly as a substitute for natural gas. Compared to landfilling, municipal solid waste gasification provides between 07 and 14 M British thermal units per ton, and between 0.33 and 0.66 tons of carbon equivalent emissions per ton of waste, with a treatment cost of approximately 50 $/ton (Sabri, Mahmoud, & Abou, 2018, p. 19).

Pyrolysis: This is the process of decomposing biomass at the temperatures up to 550 °C in the absence of oxygen (Wang, Elliott, French, Deutch, & Lisa, 2016, p. 02) to break down organic materials into three types of energy resources: 35% solid charcoal, 40% biofuel (both storable), and 10 % synthetic gas, which is burned during the pyrolysis process. Pyrolysis produces fewer air polluting emissions, is safer, less contaminating than incineration, and more efficient (70 % versus 40 %). Pyrolysis also allows the direct use of its products. For example: a plant in the UK combines pyrolysis with recycling and compost production, with a capacity of 200,000 tons of waste per year, of which 118,000 tons are used to generate electricity at about 1500 Kwh/ton. The cost of treating waste using this method is approximately 50 $/ton (Sabri, Mahmoud, & Abou, 2018, p. 20).

5. Advantages of waste-to-energy generation:

About 15 % of treated waste worldwide is incinerated for energy recovery, with most recovery plants located in developed countries. However, many developing countries have become interested in this strategy because it provides a source of energy, allows the disposal of large amounts of non-recyclable waste, and reduces the quantity of waste sent to landfills, an important advantage in areas with limited landfill capacity. These projects also improve public health and safety by removing waste from public dumps (EPA, 2021, p. 131). Incinerating waste to generate energy has several economic and environmental benefits compared to landfilling. It reduces waste volume by approximately 90 % (Khidr, 2024), some residues from incineration can be recycled (especially ferrous and non-ferrous metals, as well as bottom ash used as roadbed materials) (EPRS, 2015, p. 04), it also lowers energy import costs in non-oil-producing countries and improves urban cleanliness (Directorate of Environment, 2019). WTE electricity generation contributes to revenue from the sale of electricity, hot water, and metals. In oil and gas producing countries, it can fee quantities of these resources for export or for uses that generate higher added value than burning them for electricity. On the other hand, preparing landfills sites requires large areas of land and is a costly process, with expenses exceeding 500 M$. Transporting waste to distant locations is also expensive compared to building a WTE incineration plant, which achieves significant cost savings. For example, in Canada, the "Frankfurt plant" generates annual municipal revenues of $08M Can from electricity sales and 300,000 $ from the sale of iron and other metals (Elhadji, 2019). In Azerbaijan, the "Baku plant" saves the country from burning 100.000 tons of oil per year (ISDB, 2020). These plants can also create substantial employment opportunities, estimated at around 28,000 direct jobs and an equal number of indirect jobs in Europe (EPRS, 2015, p. 04).

Furthermore, WTE plants contribute to providing a sustainable and reliable renewable fuel source compared to wind and solar power, and require less land per megawatt compared to other renewable energy sources. Waste is converted into ash, liquids, gases, and solids that can be used as clean fuel in just a few hours, whereas it takes up to 25 years to decompose in landfills (Directorate of Environment, 2019). The gases emitted from waste incineration are lighter than those produced from burning coal or oil to generate the same amount of electricity, avoiding about 32,000 tons of emissions annually when biomass is burned instead of coal to produce the same electricity output (Sabri, Mahmoud, & Abou, 2018, p. 19). The WTE plants also provide tourism benefits. For example, the "Mashima plant" in Japan resembles an amusement park, turning the area into a tourist destination despite its industrial nature (Elhadji, 2019).

The importance of WTE recovery has increased with the intensification of the global crisis that began in late 2021, as economic recovery after the COVID-19 pandemic led to arise in global energy consumption. All markets for oil, natural gas, and coal suffered from supply shortages, resulting in price increases due to higher demand against limited supply (Yergan, 2022, p. 10). Some countries plan to expand their reliance on waste energy in both quantity and quality, making it the third-fastest growing type of renewable energy in terms of growth and contribution to energy production (Directorate of Environment, 2019). In Switzerland, for instance, energy recovery from waste is the second largest source of renewable energy generation after hydroelectric plants (OFEV, 2016, p. 25). Globally, the number of WTE plants exceeded 2450, with a total waste treatment capacity of approximately 368 M/tons/year as of 2018, and it is estimated that more than 2700 plants will be operational by 2028 (ADB, 2020, p. 01).

6. Factors to consider in waste valorization:

Waste to energy technologies can improve waste management in rapidly growing cities in developing and emerging countries. However, their implementation is complex and requires taking several factors into account, this includes:

High investment and operating costs: These plants may be economically viable thanks to tipping fees, electricity sales, and other associated products such as recovered metals. However, the plant may take several years to become profitable, and in some cases, the revenues from energy production may not be sufficient to cover operating costs. Therefore, municipalities need to seek additional sources of financing. In addition, energy production from solid waste may not always be the most competitive option due to fluctuations in electricity prices (EPA, 2021, p. 132).

Lack of financial support and institutional capacity: There is often insufficient financial support, a lack of policies related to energy recovery projects, week coordination between government bodies, limited environmental regulatory and inefficient waste collection systems

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(UNEP/ISWA, 2024, p. 25). Furthermore, source separation of waste remains limited, even though it is a basic requirement for anaerobic digestion (GIZ, 2017, p. 13).

Technological complexity and operational risks: WTE projects involve technological complexity and significant operation risks, due to the variability in the composition of municipal waste streams, differences in raw material quality, and the need for advanced systems for process control and monitoring. Selecting and integrating appropriate conversion technologies requires expertise in engineering, chemistry, and waste management, while ensuring equipment reliability, efficiency, and safety (SALGA, p. 09).

Management of emissions and solid residues: WTE plants generate residues, especially bottom ash and fly ash, which must be handled properly. It is important for municipalities to have air monitoring systems and appropriate enforcement mechanisms to ensure that these plants comply with regulatory standards and emission limits (EPA, 2021, pp. 132-133).

Waste quality requirements: One of the key issues to consider is the high moisture content in organic waste and the presence of inert materials. In India, for example, the presence of inert materials in mixed municipal solid waste, along with other factors like insufficient waste quantities and lack of due diligence by investors and the public sector, has led to operational failures in several thermal WTE plants. Seasonal variations in waste composition may also reduce its combustibility, and waste quantities can vary depending on seasons and natural disasters. Therefore, the risk associated with variations in both the quality and quantity of waste must be carefully assessed (UNEP, 2019, p. 26).

Labor requirements: The establishment and operation of WTE plants require the employment of qualified and skilled workers, as well as proper training of staff (EPA, 2021, p. 133). It is also important to consider the livelihoods of workers in the informal sector who depend on the availability of recyclable materials in waste (GIZ, 2017, p. 13).

Conflicting long-term commitments: The construction and operation of WTE plants require long-term commitments from municipalities. These commitments may not always align with other local priorities, such as reducing waste generation, since lowering the amount of waste produced means a reduction in the raw materials needed for these plants. In many cities, WTE projects may also compete with recycling efforts for materials that have high calorific value (EPA, 2021, p. 133).

Local opposition and resistance: WTE projects may face resistance and opposition from local communities, environmental groups and others. Public perceptions of WTE technologies, misconceptions about air emissions and health risks, and lack of trust in government and sector stakeholders can all undermine projects acceptance and hinder their implementation (SALGA, p. 09).

II. The legislative framework and financing mechanisms of waste management in France

Waste management in France is based on a dual approach that combines legislative firmness with financial sustainability.

1. The legislative framework of waste management in France:

The legal framework related to waste in France covers three main aspects: regulatory laws, decentralization and the powers of municipalities, and the principle of the waste hierarchy. The fundamental principles of waste management in France are derived from European Union law, and the principles of European regulations have been included into the French Environmental Code in the section related to waste prevention and management (Eastman Concertation, 2024, p. 01). These regulations are based on the European Waste Framework Directive 2008/98/EC issued on November 19th, 2008, which made the "waste/product" duality a decisive legal and economic issue for stakeholders in waste recycling and recovery, through the establishment of an administrative procedure for removing waste from its classification as "end of waste" based on various criteria (Enckell & Carré, 2015, p. 11). In addition, it clarifies the number of concepts by providing clear definitions (waste, prevention, management, reuse...), requires the implementation of waste prevention and management plans at the national level, emphasizes the "polluter pays" principle and the principle of "producer responsibility", and establishes a hierarchy of waste treatment methods. Decree No. 2010-1579 of December 2010 included various provisions to align with European law and transpose the Waste Framework Directive into French law (Eastman Concertation, 2024, p. 01).

Among the laws related to waste management in France, we mentioned the following:

The Energy Transition for Green Growth Act of 17 August 2015 (LTECV): It places contribution to environmental and resource preservation among its main pillars. It therefore encourages waste reduction and prevention of the source, sorting, and recovery. This approach is consistent with the European parliament's "circular economy package", which promotes recycling targets (ADEME, 2017). The law introduced new guidelines and objectives for waste reduction and management, particularly in Title IV: "fighting waste and promoting the circular economy from product design to recycling". These include developing a specific regulatory framework for energy production units using solid recovered fuel to ensure energy recovery from non-recyclable waste, and extending sorting instructions to include all plastic packaging (Eastman Concertation, 2024, p. 02). It also provides the framework for joint action between citizens, institutions, regions and the state, while setting medium and long-term objectives, including: reducing fossil fuel consumption by 30 %, increasing the share of renewable energy to 32 % of final energy consumption and 40 % of electricity production, diversifying electricity production and reducing the share of nuclear energy to 50 %, reducing waste sent to landfills by 50 % by 2025, and reaching a carbon value of 100 € by 2030 for the carbon component integrated into local taxation rates on energy product consumption. This helps guide medium and long-term investments and behaviors towards reducing fossil fuel consumption and greenhouse gas emissions (MEEM, 2016, p. 07).

The circular economy road map of 2018: It sets out 50 measures developed through extensive consultations around four main areas (better production, better consumption, better waste management, and mobilizing all stakeholders), in order to translate the objectives of the LTECV law into practice. These measures include simplifying and harmonizing waste sorting rules across the country, adjusting taxation to make waste recovery less costly then disposal, and achieving 100 % recycled plastic by 2025 (Eastman Concertation, 2024, p. 02).

The circular economy package 2018: adopted by the European Commission in the form of four directives setting new targets, such as recycling 65 % of municipal waste and 75 % of packaging waste, limiting landfill disposal of municipal waste to 10 % by 2030, and banning the landfilling of separately collected waste (ADEME, 2023, p. 10).

The Energy and Climate Law of 2019: defined France's renewable energy targets for the 2030 horizon, aiming to reach 33 % share of renewable energy in total final energy consumption, distributed by use as follows: 40 % electricity, 38 % heating and Cooling, and 15% transport. By 2022, the achieved shares were 28 % for electricity, 27.2 % for heating and cooling, and 8.9 % for transport (Eguienta, et al., 2023, p. 07).

The Anti-Waste Law for a Circular Economy (AGEC) 2020: aims to recover energy from at least 70 % of waste that cannot be recycled by 2025 (KYU Associés, 2021, p. 146).

National waste prevention programs: France has launched successive national programs covering the periods 2009-2012 and 2014-2020. The latter defined prevention as follows: "waste prevention encompasses all stages of a product's life cycle, from production and consumption, before the operator or society assumes responsibility for the waste, starting from raw material extraction to reuse or deployment. Reducing the amount of waste through reuse not only avoids the negative impacts associated with waste treatment but also those arising from the production of the product replaced by the reused product (such as fossil fuel consumption, energy resources, etc...)" (AMORCE/ADEME, pp. 33-34). The 2021-2027 Waste Prevention Program serves as a concise tool summarizing the national regulations and objectives established by law. It also includes operational measures enabling stakeholders (local authorities, companies, and others) to achieve these objectives. This program is renewed every six years to account for legislative changes and to update the targets (Eastman Concertation, 2024, p. 03).

Decentralization and municipal authorities: In 2011, responsibilities were reorganized to clarify the roles of the state, administrations, and municipalities in waste management. The state retained guidance functions, the administrations were tasked with planning, and data collection and processing were delegated to municipalities and inter-municipal corporation bodies. Furthermore, complex organizational structures were established at the local level to balance cost efficiency with the primary responsibilities assigned to municipal groups. The programming system follows a hierarchical planning process, beginning with national plans, which are divided into original plans, and subsequently implemented through municipal-level plans (Cour des comptes, 2022, p. 27).

The waste hierarchy principle: The environmental code places waste prevention at the top of the hierarchy of waste treatment methods (Article L. 541-1). This prevention is considered a key element for the circular economy, as it promotes more efficient use of resources, reduces waste generation at the source, and extends the lifespan of products (MTECT, p. 01). It is followed by reuse, then recycling, then energy recovery, and finally disposal (FEDR, 2017, p. 12). Article R541-8-1 defines solid recovered fuel as "non-hazardous solid waste, consisting of waste that has been sorted in a way that allows the extraction of the fraction that can be recovered as material under prevailing technical and economic conditions, and prepared for use as fuel. From this definition, several important elements should be noted: solid recovered fuel is waste, it consists of non-hazardous waste that cannot be reduced or recycled, and its production requires sorting and preparation steps" (Jacob, 2022, p. 02). Meanwhile, the decree issued on 2016, defines co-incineration plant for solid recovered fuel as: "any fixed or mobile technical unit whose, main purpose is the production of energy or materials, which uses solid recovered fuel as a regular or supplementary fuel, or subjects it to thermal treatment for the purpose of recovery through combustion, oxidation or other processes, such as pyrolysis, gasification, or plasma treatment, provided that the resulting materials are used directly as fuel" (Legifrance, 2020). When this fuel is used to produce heat and or electricity through turbines, it is considered energy recovery, similar to methane recovery, gasification, and pyrolysis processes. Therefore, in order to respect the hierarchy of waste treatment methods, waste can only be converted into solid recovered fuel when reuse and recycling are no longer possible, in such cases, recovering it as solid fuel is prepared over disposal. Although both waste incineration with heat recovery and the recovery of waste through the combustion of solid recovered fuel are forms of energy recovery, they differ in their objectives. The primary aim of incineration is waste treatment, with energy production as a secondary outcome. In contrast, the combustion of solid recovered fuel has energy production as its main objective (Jacob, 2022, p. 03). Among the reasons for this hierarchy (UNEP/ISWA, 2024, p. 25):

- Many governments are increasingly prioritizing waste reduction, reuse, and recycling, as these are considered more cost-effective and more environmentally friendly than the use of WTE technologies. On the other hand, this technology remains a subject of debate, as many argue that thermal treatment methods reduce the incentives to minimize waste generation.
- Waste to energy represents a linear use of resources, since the materials that are burnt cannot be recovered or used again.
- Thermal incineration technologies have limitations when it comes to treating wet food waste, which may dominate municipal waste streams.

However, the industry argues that incineration can usefully complement recycling when the poor quality of waste makes recycling impossible. It is also noted that some countries with high recycling rates (e.g. Germany and Sweden) incinerate a large share of their waste while keeping landfill used to a minimum (EPRS, 2015, p. 04). Regarding the issue of non- reusability of burnt materials, as well as the problem of moisture that hinders waste incineration, the experience of Azerbaijan (represented by the Baku plant) shows that natural gas can be used to generate electricity when the moisture content of waste varies from one season to another (ISDB, 2020).

2. Financing of waste management in France:

The financing of the energy transition of waste in France relies on various sources, which can be summarized as follows:

2.1.Financial support:

Achieving the objectives of the LTECV law and the guidelines of the roadmap toward a 100 % circular economy requires the creation of new treatment capacities, which in turn demands significant investments. Investment needs at the national level, within the framework of the "Waste Reduction and Recovery Plan 2025" issued in 2016, were estimated at 4.5 bn€ over the period 2015- 2025 (MTES, 2019, p. 45). The French Agency for Ecological Transition (ADEME) is responsible for supporting the implementation of French policies, with a particular focus on waste reduction, supporting innovation and research and development, and investing in recycling and recovery. In 2012, the agency provided nearly 2000 grants for local projects aimed at improving waste management, ranging from project studies to investments of all sizes. It also works to strengthen the involvement of producers of consumer goods in the collection, recycling, and treatment of these goods after use, in line with the principle of extended producer responsibility.

More than 18 extended producer responsibility schemes have been developed over the past 20 years to organize and finance the management of certain types of used products such as household packaging, batteries and accumulators, and waste electrical and electronic equipment (ADEME, 2013, p. 01). The energy transition financing fund (allocated a budget of 1.5 Bn€) aims to strengthen existing mechanisms (such as heat funds) and to support new projects, particularly those located in positive energy territories for green growth, zero waste and anti-waste areas, and the "breathable cities" (MEEM, 2016, p. 06). In 2021, renewable energy accounted for 11 % (188 M€) of total public spending on energy related research and development. This spending was mainly concentrated in two sectors: Solar energy (40 %) and biomass (33 %), with a primary focus within biomass on biofuels, and to a lesser extent, biogas (Eguienta, et al., 2023, p. 30).

Financial assistance also includes:

European Regional Development Fund (ERDF): The European Union offers investment support through this fund, on the condition that the member state or region requesting this support has established waste management plans in accordance with directive 2008/98/EC on waste and its hierarchy (MTES, 2019, p. 46).

Circular economy fund managed by ADEME: In 2023, the French government nearly doubled the fund's capital, increasing it from 164 M€ to 300 M€. Over half of this amount (54 %) is allocated to recycling operations and energy recovery from recovered solid fuel, sorting and preparation centers, and professional waste disposal sites, while 15 % is devoted to organic recovery, including methane (ADEME, 2024, p. 06). The fund provides support for most operations that contribute to achieving the waste policy objectives set by the LTECV law and confirmed by the 100 % circular economy roadmap. Decisions on aid and its amounts depend on the nature of the activities (preparatory studies, communication, awareness campaigns, investments by local authorities and companies, etc.) and the characteristics of the submitted operations (waste collection for recovery, recycling, organic materials, and energy recovery) (MTES, 2019, p. 46).

2.2.Tax and financial incentives:

France has introduced a set of tax and financial incentives designed to attract investments and reduce barriers for WTE projects, this includes:

Tax incentives: waste management user fees are direct charges and taxes levied on individuals, households, and businesses in exchange for waste services provided. This type of financing aims to internalize the external impacts associated with waste generation, transport, and disposal. Two methods of charging user fees are documented in the literature: "Pay as you throw" (PAYT) and flat-rate fees (Ezeudu & Bristow, 2025, p. 3068). France has adopted a tax policy that encourages the use of waste for energy production and reduces landfilling and incineration. According to the circular economy roadmap, taxes are adjusted to make waste recovery approximately 10 €/ton cheaper than disposal. Therefore, the Finance Act (2019) increased the general tax on polluting activities applied to waste treatment facilities (TGAP), starting in 2021. The nominal maximum tax rate continues to rise, reaching 65 €/ton in 2025 For landfill activities, 25 €/ton without energy recovery and 15 €/ton with energy recovery for thermal treatment. Furthermore, the VAT apply to the collection, sorting, and recycling of separately collected household waste by private service providers used from 10 % to 5.5 % starting in 2021. Finally, the administrative fees deducted by

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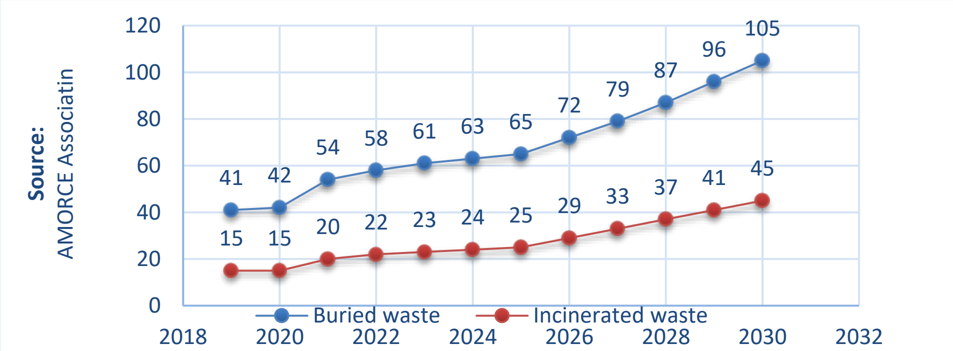
the state from the incentive household waste collection tax (TEOMI) were lowered to 3 % compared to 8 % during the first 5 years of the TEOMI transition (ADEME, 2024, p. 36). Current estimates indicate that the general tax on pollutant activities (TGAP) generates around 1.2 € for the French government. Local authorities bear (directly or indirectly) about 70 % of this amount (850 M€), which is ultimately paid by taxpayers. The rates of this tax are expected to increase between 2019 and 2030 by an average of 400 % for all local authorities. According to calculations by "Intercommunalités de France", this tax will generate more than 1.9 bn€ in 2030, of which 1.35 bn€ will be borne by local authorities. These estimates are based on the assumption that the quantities of incinerated and landfilled waste will remain stable by 2030, and the 80 % of waste to energy units will have an energy efficiency exceeding 65 % (Intercommunalites de France, 2025). The figure below shows the increase in TGAP rates on landfill operations compared to incineration over the period (2019/2030).

Figure No. (01): Evolution of TGAP costs by treatment method in €/ton



Source: (Gayraud , 2025)

Public private partnership (PPP) contract: Article L. 1112-1 of the French public procurement code define a PPP contract as a "public contract. Aimed at entrusting an economic operator or a group of operators, with a comprehensive task that includes: the construction, transformation, renovation, dismantling, or demolition of structures, equipment, or intangible assets, necessary for a public service or for carrying out to task of public interest, with the operator bearing all or parts of the financing. The PPP contractor is responsible for managing the project related to the planned operation" (Legifrance, 2019). One of the main advantages of public-private partnership projects in waste management is the sharing of financial risks between public and private actors (wastetrade, 2026). The experience of the Asian Development Bank confirms that public-private partnerships are among the most suitable financing models for this type of investment. The bank plays a major role in supporting its member countries by helping to mitigate risks, managing public-private partnerships in the WTE sector, providing investments and/or loans to developers entering WTE markets, including WTE projects within its sovereign operations (ADB, 2020). In China, for example, the municipality of Wanzhou partnered in 2002 with a local private contractor to build and operate a waste incineration plant for energy production and for a period of two years. After that, the government took ownership and management of the plant without providing any compensation to the private investor. The plant also receives service fees from the municipality for the disposal of solid waste (EPA, 2021, p. 132).

Public Service delegation contracts: Local authorities, their groupings, or their public institutions may entrust waste management to one or more economic operators through a public

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service delegation agreement (Legifrance, 2026). The operator's remuneration depends on the operating results of the infrastructure or service, and the risk standard is a key element in the financial standard (Collectivites Locales, 2026).

Purchase agreements: The state guarantees investors the sale of electricity or heat generated from waste recovery to the national grid at fixed and guaranteed prices over long periods (often 20 years). This reduces "energy Market" risks and ensures stable investment returns (Legifrance, 2026).

In addition to the above, local authorities still pay around 105 €/ton to incineration plants, even after accounting for revenues and subsidies generated from incineration (Brouillard, 2025).

Third axis: Economic performance of waste to energy in France

This part of the study focuses on three elements: the amount of energy produced the energy efficiency indicator, and the impact on employment.

1. **Energy production from waste:**

In 2022, total energy consumption in France reached 2544 Twh, of which 345 Twh came from renewable energy sources (Eguienta, et al., 2023, p. 10), classified by type and source in the table below, which shows that waste represents one of the sources of energy production in France.

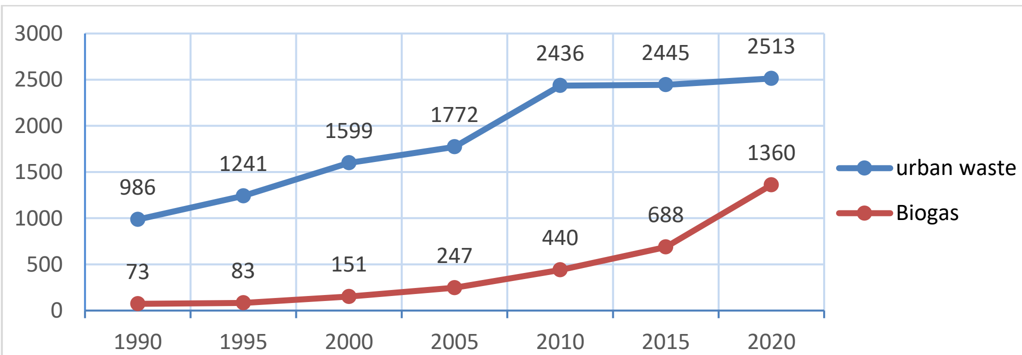
Table one: Energy consumption by type and source in 2022

Primary energy by type	%	Renewable energy by source	%
Nuclear energy	36	Wood	32.9
Oil products	30	Hydropower (water)	13.2
Natural gas	16	Heat pumps	12.4
Renewable energies	14	Biofuels	11.2
Coal	3	Wind	11
Non-renewable waste	0.8	Solar energy	06
		Biogas	5.5
		Renewable waste	4.2
		Others	3.7

Source: (Eguienta, et al., 2023, pp. 06-10)

The following figure shows that waste constitutes a stable source for energy production, as production recorded continuous growth over the period (1990- 2020).

Figure (02): primary energy production related to waste in ktoe



Source: (ADEME, 2023, p. 56)

In 2020, energy production from waste treatment reached 22364 Gwh, of which 15285 Gwh were generated by municipal solid waste incineration units (MSWI), 1775 Gwh by non-hazardous waste landfill facilities (known as ISDND), and 5304 Gwh by waste-to-methane conversion units (ADEME, 2023, p. 55). A continuous increase in total electricity production was recorded over the period from 2004 to 2020, while thermal energy production showed a growing trend starting from 2010, after experiencing a consecutive decline between 2004 and 2008 (see table 2). The growth of WTE is linked to the rise in electricity prices. On the other hand, the decline in metal prices on global markets has significantly affected recycling activities. For example, the turnover of the company Recyclex that specializes in the recovery of zinc and lead from plastic decreased by 20 % in 2019 (Businesscoot, 2023, pp. 40-41).

Table 2: Evolution of energy production in the MSWI and the ISDND in Gwh

Year/ Energy		2004	2006	2008	2010	2012	2014	2016	2018	2020
Electrical	MSWI	3241	3206	3489	3657	4214	4360	4360	4183	4320
	ISDND	387	497	454	858	953	1080	1130	926	1208
total Production		3628	3703	3943	4515	5167	5440	5492	5109	5528
Thermal	MSWI	8331	6700	6573	7589	8494	9799	9799	10177	10965
	ISDND	61	114	129	296	294	640	604	565	567
Total production		8392	6814	6702	7885	8788	10439	10403	10742	11532
Total energy		**12020**	**10517**	**10645**	**12400**	**13955**	**15879**	**15895**	**15851**	**17060**

Source: (ADEME, 2023, pp. 56-57)

Incineration is the main method for generating energy from waste. Between 2000 and 2020, the amount of waste incinerated for energy production grew by 40%, and reached 14.5 M tons (ADEME, 2023, p. 55). The total cost of incineration was estimated at 1.7 bn€, with an average cost of 116 €/ton (Brouillard, 2025). In 2022, France had 116 WTE incineration plants. About 1/3 of these facilities produced both heat and electricity using combined heat and power turbines. Waste incineration for energy recovery accounted roughly 1/3 of household waste. The distribution of incarnated waste by type of energy produced was 14 % for electricity only, 19 % for heat only and 64 % for both heat and electricity (Eguienta, et al., 2023, p. 60). Concerning methanization, France ranked third in terms of the number of biogas facilities in 2019, after Germany (11000 facilities out of over 18000 in Europe) and Italy. By 2022, France had 1607 facilities, 1317 operational methanization units produce biogas primarily from agricultural waste, while 98 units recover biogas from urban or industrial wastewater treatment plants and 192 units recover it from non-hazardous waste storage facilities. Among these facilities, 12 % produce heat only, 60 % produce both electricity and heat, and 28 % inject bio-methane into the natural gas network (DDT de l'Oise, 2023). The treatment of the amount of household and similar (estimated at 1M tons) collected in 2022 was as follows: 8.76 at household and similar waste sorting centers, 5.46 at non-hazardous waste sorting centers for economic activities, 6.788 by composting, 0.341

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by methanization, 14.319 by incineration with energy recovery, 0.0548 by incineration without energy recovery, 14.248 at ISDND, 1.879 by mechanical-biological treatment facilities and 2.56 at bottom ash maturation and processing facilities (AMORCE, 2025, p. 17).

Directive 2000/76/EC (on waste incineration) made WTE conversion one of the most strictly regulated and supervised industrial activities (Ugbong, et al., 2025, p. 27). The implementation of these regulations in waste management facilities led to a significant reduction in pollutant emissions between 1990 and 2003, with dioxin emissions from waste treatment decreasing markedly by 90 % due to the gradual closure or upgrading of old incinerators (ADEME, 2023, p. 77). France does not only set production standards for fuel but also enforces strict monitoring through the Continuous Emission Monitoring System, which transmits the recorded data to the competent authorities in real time. This system is known as an "automated flue gas monitoring system", "continuous flue gas emissions monitoring system" or the "online flue gas monitoring system" (YE, 2026).

In 2021, France was the second largest producer of renewable energy in Europe after Germany. It ranked first in heat pumps, second in hydroelectric power, solid biomass, renewable waste, and geothermal energy, and 14th out of 27 European countries in terms of the share of final total energy consumption produced from renewable sources (Eguienta, et al., 2023, p. 73).

2. Energy efficiency index (R1 Formula) :

The EU waste directive 2008/98/CE allows municipal waste incinerators to be classified as recovery operations provided they contribute to the generation of energy with high efficiency to promote the use of waste to produce energy in energy efficient municipal waste incinerators and encourage innovation in waste incineration. The non-exhaustive list of recovery operations presented in Annex II defines **R1** as a recovery operation, which means "Use principally as a fuel or other means to generate energy" (European Commission, 2011, p. 05). This includes incineration facilities dedicated to the processing of municipal solid only where their energy efficiency is equal to or above : 0,60 for installations in operation and permitted in accordance with applicable Community legislation before 01/01/2009, and 0,65 for installations permitted after 31/12/2008 (OJ of the EU, 2008, p. 24) . Using the following formula (De Chefdebien, , 2010, p. 12):

$$R1 = (Ep - (Ef + Ei))/(0.97 \times (Ew + Ef)$$

In which:

Ep**:** annual energy produced as heat or electricity, It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)

Ef: annual energy input to the system from fuels contributing to the production of steam (GJ/year)

Ew: annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)

Ei: annual energy imported excluding *Ew* and *Ef* (GJ/year)

0.97**:** is a factor accounting for energy losses due to bottom ash and radiation.

3. Impacts of waste-to-energy on jobs and skills:

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Today, the global renewable energy sector employs more people than the fossil fuel sector. According to the International Renewable Energy Agency (IRENA), an investment of 1 M$ in renewable energy creates nearly three times the jobs that the same amount creates in the fossil fuel sector. Increasing investment in the energy transition could increase the number of jobs in the renewable energy sector to about 43.3 million by 2050. Therefore, the growth of renewable energy compensates for the loss of jobs in the conventional energy sector. The 7.4 million jobs lost due to the energy transition would be replaced by 19 million new jobs (OFATE, 2021, pp. 11-13). In France, among the objective of the LTECV law is the creation of short-term jobs, estimated at 75.000 jobs in the energy renovation sector, about 30.000 jobs in the renewable energy sector and more than 200,000 jobs by 2030 (MEEM, 2016, p. 06). According to the ''Waste Reduction and Recovery Plan'' of 2025, investments in waste management will lead to economic growth, providing 7.500 permanent jobs to operate the new facilities and 20.000 temporary jobs for the construction and Equipment phase of the facilities over 10 years (MTES, 2019, p. 45). It should be noted that in 2020, the number of jobs in renewable energy and recycling reached 85,000, 0.7 of which were in household waste (Eguienta, et al., 2023, p. 32). ADEME estimates that processing 10,000 tons of waste creates full-time equivalent jobs as follows: 3-4 jobs if recovered through incineration, composting, or methanation, 11 jobs if sorted, 50 jobs if complex used products are dismantled, compared to only one job if landfilled (Rebaud , 2016, p. 08). Among these Jobs (Céreq, Décembre 2018, pp. 29-37):

Waste collection and sorting: In this field, employers face hiring difficulties related to the poor image of these occupations and the nature of the work offered. Employment and training policies have also been limited to on-the-job training and informal knowledge transfer. Therefore, these policies focused mainly on employees without formal qualifications, whereas organizational changes and sector industrialization require jobs with higher skill levels.

Waste processing and recovery: Jobs in this field require more qualifications then collection and sorting jobs, particularly due to stricter safety standards and the need for tracking and ensuring the quality of recycled raw materials. To deal with the skills gap, several professional qualifications certificates have been introduced.

Maintenance, quality and safety: Technological progress and the development of increasingly complex technical processes affect the nature of maintenance work, given a new dimension to the three main tasks of maintenance professionals (inspection, prediction, and repair). In the energy recovery sector, technological developments enable "predictive maintenance". However, it is difficult to attract and retain employees with skills or experience in electrical engineering.

Administrative and organizational professions: These include weighbridge operator and sales agent. In case of a skills shortage, employers can benefit from professional development programs offered by industrial sectors; 283 professional development contracts were signed in 2017, 28 % of which were for sales positions.

Future jobs: Employment opportunities in the waste treatment and recovery sector remain very promising due to regular regulatory incentives and evolving environmental considerations in consumer choices. Skills capable of confronting the challenges of improving recycling performance are gradually emerging. Emerging professions include waste assessor due to demolition activities. The waste assessor combines skills in the construction sector and in waste

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management. They must identify the nature and volume of materials and equipment, determine reuse opportunities, estimate the quantity of materials recovered or disposed of, and assess management costs. Another emerging role is this scheduler/ logistician, responsible for optimizing resource flows in waste sorting and treatment centers. At this level, the end client is the industrial company that purchases the recycled raw materials and integrates them into its production process. The logistician participates in organizing waste collection routes and the distribution of final products resulting from treatment. The scheduler/ logistician must have commercial acumen, strong communication skills with clients, and solid technical knowledge.

Conclusion:

Through the study of the French experience in waste to energy recovery, we concluded that this process requires significant financial and managerial capacities as well as qualified human resources. Therefore, it needs supporting and incentivizing strategies, along with effective framing and organization that reflect the political will to utilize waste as one of the alternatives for producing clean and renewable energy. However, despite the importance of this process in reducing reliance on conventional energy alternatives, it is not considered the primary or optimal option is strategies for managing and treating waste in France. It comes after measures that follow what is known as the hierarchy of choices. This is because WTE recovery can hinder prevention efforts that encourage reducing waste of the source, rationalizing the consumption of goods and energy, and it competes with recycling operations.

WTE recovery contributes to significant economic, social, and environmental benefits, such as helping to dispose of non-recyclable waste, preserving natural resources, reducing emissions compared to conventional energy production methods, and contributing to energy security. The development of WTE technologies reduces reliance on conventional energy sources, and thereby it enhances opportunities to create new jobs in the field of waste management and its conversion into clean energy, and thus generating employment. Waste management involves multiple stages, from sorting to disposal or landfilling, and each of these stages requires a variety of skills to ensure proper waste management and, consequently, the success of energy recovery from the non-recyclable portion of the waste. This process has also led to the emergence of new professional specialties, such as waste diagnosticians and schedulers/logisticians.

This study also showed that generating energy from waste can address two problems simultaneously: the proper disposal and management of waste, and on the other hand, contributing to solving the problem of providing energy to as many citizens as possible, especially in non-oil producing countries or those with limited or scarce natural resources. This allows such countries to reduce their energy import bills, lower energy production costs compared to other sources, particularly oil and gas, reduce the depletion of energy resources and contribute to environmental sustainability. Furthermore, waste can serve as a stable and continuous energy source, unlike other renewable sources such as solar, hydro, and wind energy, which are variable and dependent on climatic conditions. Moreover, WTE projects represent profitable investment opportunities for the private sector. However, these projects May face waste shortages due to competition from recycling companies or expansion of recycling activities. This latter requires finding alternatives to local waste in order to continue energy production and ensure that these facilities do not halt operations.

The French experience has shown that the shift from waste disposal to energy production is not merely a technical choice, but an integrated system requiring the synergy of three dimensions: strict French and European legislation, innovative financial engineering, and precise technical monitoring. It also links environmental responsibility with economic profitability. Drawing upon the results of this study, we propose a set of recommendations that may help decision-makers design appropriate strategies for waste management and its energy recovery:

- Moving from a narrow environmental perspective to a comprehensive investment perspective, and treating waste as a resource then merely materials for disposal.
- The success of WTE conversion depends on preparing plans that focus on assessing current and future waste flows (their quantity, composition, types, and characteristics), while taking into account demographic and social changes. This helps in selecting the most appropriate pathways for waste management and its energy recovery. It also requires a development of clear and effective strategies that organize waste handling in terms of collection, sorting sort, transport and treatment. While ensuring their adjustment and development in response to future changes in waste composition, to ensure the proper sorting of recyclable materials at the source, and to preserve waste designated for energy recovery while maintaining its calorific value.
- Establishing appropriate and strict legal, legislative and environmental frameworks for waste management: adopting the waste hierarchy, reinforcing the "polluter pays" principle, defining producer responsibility, regulating and monitoring WTE recovery processes, defining the responsibilities of municipalities and their role in the success of waste management and its energy recovery, while providing a common framework for cooperation between citizens, institutions, local authorities and the government.
- Facilitating support and financing mechanisms for WTE projects, such as public service delegation contracts, purchase agreements, public-private partnerships and partnership agreements with regional and international financial institutions (as illustrated by the experiences of France, China, and the Asian Development Bank).
- Activating renewable energy incentives by integrating WTE plants into the national energy strategy, in order to ensure fair purchase prices for electricity and heat.
- Lowering taxes and fees on investments in WTE projects, and increasing them on pollution and waste management activities without energy recovery.
- Preparing WTE facilities to switch to natural gas-based production to avoid energy generation interruptions due to waste shortages or seasonal moisture variations.
- Raising awareness among economic sectors about investment opportunities offered by waste and its treatment, especially in the field of energy recovery. Introducing available technologies and techniques in this area, while ensuring the availability and accessibility of information on waste quantities to different stakeholders, including institutions, investors, and researchers ….
- There is a need to strengthen training in the field of energy recovery and to orient university education and scientific research activities toward the circular economy, green economy, and renewable energy.
- Adopting continuous monitoring systems and digital transparency in reporting emission data in order to ensure public acceptance and environmental compliance.

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