waste

Review

Facts and Figures on Aspects of Waste Management in Middle East and North Africa Region

Qahtan Thabit [1,*], Abdallah Nassour [1] and Michael Nelles [1,2]

[1] Department of Waste and Resource Management, Faculty of Agricultural and Environmental Sciences, University of Rostock, D-18059 Rostock, Germany
[2] Deutsches Biomasseforschungszentrum GmbH, D-04347 Leipzig, Germany
* Correspondence: qahtan.thabit@uni-rostock.de

Abstract: The waste management field in Middle Eastern and North African countries suffers from multiple drawbacks and chronic problems that require strategic solutions and collaboration among various institutions. Due to a lack of data, a financial deficit, limited economic resources for the municipalities, and singular treatment processes, until recently, waste has been dealt with as garbage that needs to be disposed of, while, in a large number of developed countries, waste now represents a substantial economic resource and an important source of materials that can be reinserted into the industrial sector. This paper presents a review of several aspects and sectors that are directly related to waste generation and the current situation regarding the waste management system in the Middle East and North Africa (MENA) region in terms of composition, generated amount/capita, existing treatment routes, and institutional frameworks. Furthermore, gross domestic production and population growth are specified as critical factors governing the waste sector in the region. Such data and information will increase the possibility of drawing a roadmap to convert the current waste treatment stream into a material flow concept and circular economy. The energy sector (energy consumption) is also considered to illustrate the potential role of waste if incineration technology (energy recovery from waste) is realized as a radical solution for the waste system in the region. Following a review of the literature, the main challenges in the waste management sector that need to be solved are summarized. The novelty of this work is two-fold. First, it elucidates the connection between gross domestic product (GDP), waste composition, and waste generation. According to the literature, countries with a high GDP produce a greater amount of waste (around 1.5–2.7 kg/capita/day) with a lower organic share of waste composition of around 40%, as they have an increased lifestyle rate. Second, a review of energy consumption per capita illuminates the essential role of waste as a source of energy.

Keywords: waste management; waste generation; gross domestic production; waste-to-energy

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1. Introduction

The population growth rate is one of the key factors and indicators that predicts the amount of waste that will be generated over several decades. This will help to put in place strategic plans to tackle this increment in waste generation and build integrated waste management systems, starting from collection and transportation processes and ending with treatment streams. This factor can also be central in setting up awareness campaigns and education materials anywhere in the world for future generations to create a culture of prevention and engage in reducing, reusing, and recycling, as this is important to deal with waste as a source of raw materials. This article considers the MENA region, where the predicted population growth—according to the available literature—is large, especially for the main and mega cities (with more than one million inhabitants). Indeed, MENA has experienced the highest rate of population growth in the world over the past century. This reached a peak of 3 percent around 1980, while the growth rate for the world as a whole reached its peak of 2 percent per annum more than a decade earlier. Improvements in human survival, particularly during the second half of the 20th century, have fueled rapid population growth in MENA and other less developed regions. The introduction of modern medical services and public health interventions, such as antibiotics, immunization, and sanitation, caused death rates to fall rapidly in the developing world after 1950, while the decline in birth rates lagged behind, resulting in high rates of natural increase (a surplus of births over deaths). While the "demographic transition", the shift from high to low mortality and from high to low fertility, is well underway throughout the region, individual countries are at different stages. On average, fertility in MENA declined from seven children per woman around 1960 to three children in 2001. The total fertility rate (average number of births per woman) is less than three in Bahrain, Iran, Lebanon, Tunisia, and Turkey, and more than five in Iraq, Oman, the Palestinian Territory, Saudi Arabia, and Yemen [1–3]. Based on this rate of growth, a study was prepared by the United Nations to present historical and future data on the population in the MENA region, as depicted in Figure 1.

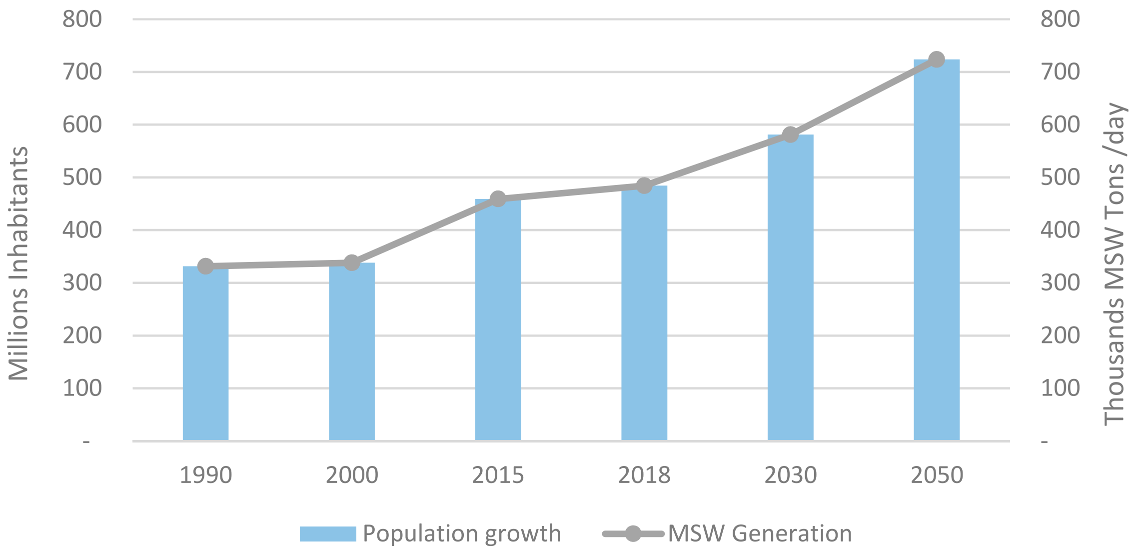

Figure 1. Population growth in MENA region countries from 1990 to 2050; the prediction for 2030 and 2050 is based on the annual growth rate [4].

Currently, more than 480 million inhabitants are living in 23 MENA region countries and the average waste generation rate is around 1 kg/capita/day [5,6]. This means that there will be more than 480,000 t of MSW generated every day. Table 1 depicts the relationship between waste generation and population in each country. Note that these data represent the current situation regarding waste generation; thus, after another 5 or 10 years, MSW amounts can be expected to grow, as shown in Figure 1. For instance, approximately 580 million inhabitants are expected by 2030, leading to 580,000 t/day of waste, and so on.

Table 1. Annual waste generation in MENA region countries in 2019–2020; data adapted from [5,7].

Country	Population	Average MSW Generation (kg/Capita/Day)	Total Amount of Waste Generation (Ton/Year) $\times 10^6$
Egypt	99,413,317	0.82	29.75
Tunisia	11,516,189	0.6	2.52
Jordan	10,458,413	0.9	3.44
Iraq	40,194,216	0.87	12.76
Algeria	41,657,488	0.9	13.68
Lebanon	6,100,075	0.6	1.34

Table 1. *Cont.*

Country	Population	Average MSW Generation (kg/Capita/Day)	Total Amount of Waste Generation (Ton/Year) × 10^6
Libya	6,754,507	0.77	1.9
Syria	19,454,263	0.5	3.55
Saudi Arabia	33,091,113	1.8	18.13
Oman	4,613,241	1.5	2.53
Qatar	2,363,569	1.8	1.29
United Arab Emirates	9,701,315	1.7	5.31
Kuwait	2,916,467	1.5	1.6
Bahrain	1,442,659	2.7	0.79
Yemen	28,667,230	0.6	6.28
Morocco	34,314,130	0.8	10.02

Rapid population growth threatens MENA's sustainable development, as the region is faced with the most severe water shortage in the world [8], as well as an unsustainable waste management system. Together, these make rapid population growth a challenge that needs to be precisely addressed and taken into consideration by countries who are drawing strategic plans for the future of new generations in terms of waste management, water supply, and energy consumption. As indicated in Table 1, Egypt has the highest annual waste generation of around 29 million ton/year from a population of approximately 99 million (making it the most populated country in the region). It can also be seen that some countries have a higher population rate than others, but the same annual waste generation; for example, Tunisia has around 11.5 million capita, while Oman has approximately 4.6 million capita, but both have the same yearly waste generation, based on average daily waste generation (kg/day.capita) of 0.6 and 1.5 (kg/day.capita) for Tunisia and Oman, respectively. Notable too is the fact that Saudi Arabia generates a larger amount of waste per annum than Iraq and Algeria. In general, Gulf countries have the highest daily waste generation rate because of their high gross domestic product (GDP).

Based on the volume of waste generated and its composition, treatment streams can be designed and planned.

To provide an updated database for researchers and decision-makers, the authors reviewed more than 85 references focusing on waste management and energy sector aspects in MENA region countries. Therefore, this article presents detailed data about the waste composition, treatment streams, and financial aspects of selected countries in the region, as well as the energy consumption/capita and renewable energy investment development. It investigates a specific scenario of energy recovery from waste as a strategic treatment solution for the current waste sector situation. Economic data were also reviewed in terms of GDP, which governs the amount of waste generation and reveals the lifestyle of each country. The data are presented in a sequence, starting with GDP to illustrate the conceptual link between the economic condition of a country and the waste generation rate, followed by energy consumption, which is essential for calculations of energy recovery from waste, and a renewable energy roadmap to display the infrastructure of energy distribution. This will reveal how important it is to involve the waste-to-energy concept in the energy sector in the region. Finally, data on the waste sector are presented to integrate all elements of this article and provide a comprehensive database.

2. Gross Domestic Product

The MENA region commands abundant human and natural resources, accounts for a large share of world petroleum production and exports, and on average enjoys a reasonable standard of living. Within this general characterization, countries vary substantially in terms of resources, economic and geographical size, population, and standards of living. At the same time, intra-regional interaction is weak, being restricted principally to labor flows, with limited trade in goods and services. MENA covers a surface of more than

15 million square kilometers and is experiencing [9] rapid population growth and high dependency ratios. The labor force has grown faster than the total population in recent years. Because more than 50 percent of the population of some countries is under the age of 15, this growth will be relevant for years to come; moreover, this increases the potentiality of the region to be a major host for investment [10]. Although the region is afflicted by harsh climates, limited groundwater and rainfall, and scarce arable land, it enjoys abundant *natural resources*. Around two thirds of the world's known crude oil reserves lie under the MENA region, with one quarter located in Saudi Arabia [11]. These facts emphasize the importance of investing in waste-to-energy projects in the MENA region. For this important part of the world, waste could represent a highly valuable resource. First, waste will be treated within an environmental framework, as waste incineration produces far fewer emissions than landfilling, which is the main treatment process in the region. For instance, each ton of MSW to be landfilled emits 840 kg CO_2, while each ton of MSW generates 415 kg CO_2 in the case of incineration [12,13]. Reflecting these various advantages, the MENA region constitutes a sizable *economic entity* and enjoys a reasonable standard of living by international standards. Real GDP growth in the MENA region is projected to rise to 4.0 percent in 2021, an upgrade of 0.9 percentage points relative to October [14]. Over the medium term, the real GDP is expected to remain below precise projections by nearly 6 percentage points, reflecting smaller output losses among oil exporters than oil importers that are broadly in line with other emerging market economies. Activity in **oil-exporting countries** is set to rebound, reflecting a carryover from the last quarter of 2020, and will be amplified by the expected pickup in activity in the second half of 2021. Higher oil prices and early vaccine rollouts support a positive outlook for many Gulf Cooperation Council economies. The recent increase in oil prices will boost confidence, supporting the non-oil GDP, which is projected to expand by 3.3 percent in 2021. The recovery among **oil importers** is expected to be sluggish in the near term, with growth projected to be 2.3 percent in 2021—a downgrade of 0.4 percentage points relative to October [14]. As can be seen from previous data and information, countries in the MENA region are divided into two main groups depending on the most important driver, "oil": exporting and importing countries. Furthermore, the economic structure is directly related to the international oil markets, which is why these countries are directly connected with oil prices and experience economic rebound when these prices start to increase. The concept of multi-income economic dependency is now applied in several countries in the region, such as Saudia Arabia and Jordan, and waste management—specifically, the waste-to-energy concept—will leave a large fingerprint on the fluency of the economy in this region, especially as this region is treating its waste directly by landfilling. This makes the region a strong candidate to integrate the waste-to-energy concept into its economy. Figure 2 illustrates the development and overlapping of GDP for MENA region countries from 2018 to 2020. As shown, oil-importing countries such as Jordan (the case study for this research) could not exceed USD 10,000, which emphasizes that these countries urgently need to adopt multi-economic strategies to increase their productivity. In other words, the oil-importing countries have exports worth only USD 365 billion, which is exactly the same as Belgium, a country of eleven million inhabitants [15,16]. Thus, GDP is a significant and key indicator of the waste generation rate. As mentioned previously, Gulf countries have the highest waste generation (kg/capita.day) as they have the highest GDP. The higher the level of wealth or development of a country (GDP), the greater its waste generation [17]. Several works have stated that for every USD 5000 increase in the real GDP, the MSW generation per person increases by approximately 0.065 t per year [18]. In terms of energy, waste can play a major role for both oil importer countries and oil exporter countries if its energy is recovered. For importer countries, energy from waste projects can reduce the energy imported and this will increase the GDP, while, for exporters, such projects can save a certain amount of crude oil (it depends on the lower calorific value of waste), which can be exported, and this will also increase the GDP.

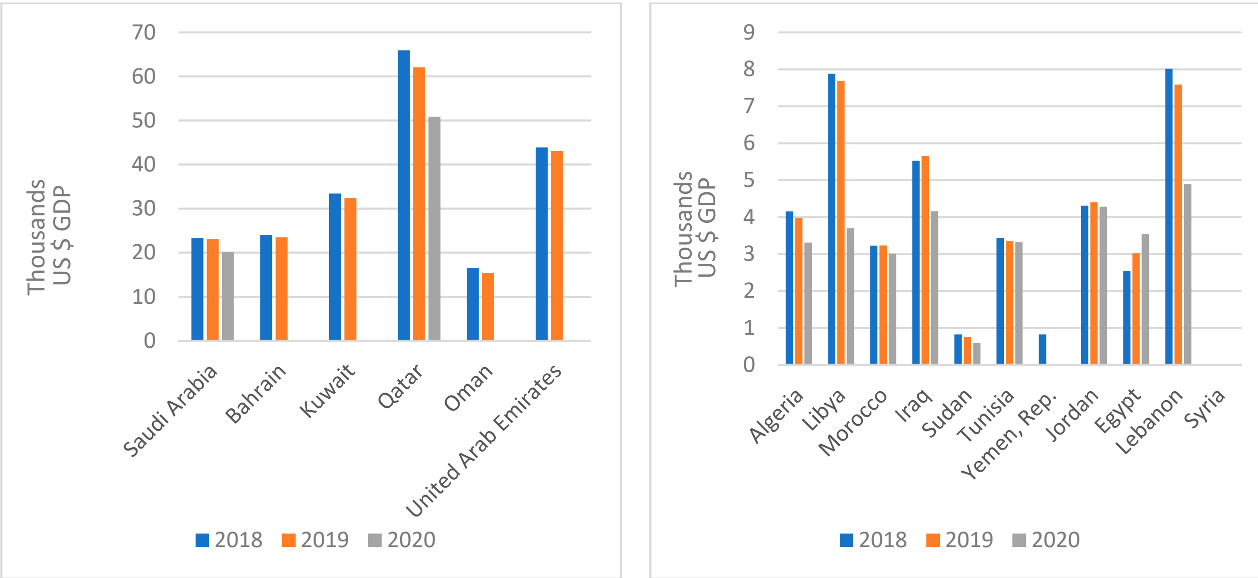

Figure 2. GDP of oil-exporting countries (**left**) and oil-importing countries (**right**); data adapted from [15,16,19].

Waste incineration can play a major role in driving the economy and affect the rate of growth. In fact, countries need to increase the rate of trading volume of goods exported and search for new sources of income, such as a waste management system; for example, regarding the trade capacity of the region in 2018 and trade balance, Jordan exhibited growth that year, but when this amount of budget is distributed across the population, there will be a deficit in GDP per capita. Because of this, and according to the most recent report by the World Bank, the substantial borrowing that MENA governments have had to incur to finance emergency expenditure on essential health and social protection measures has increased government debt dramatically. The average public debt in MENA countries has risen by almost 8 percentage points, from approximately 46% of the GDP in 2019 to 54% in 2021. Debt among MENA oil importers is expected to average approximately 93% of the GDP in 2021. Additionally, the need to keep spending—and borrowing—will remain strong for the immediate future. Additionally, this is exactly the economic situation in Jordan, where the debt of GDP is around 90%, excluding subsidies and donations.

3. Energy Consumption

The consumption rate of energy has a direct effect on the economic growth and income of a state. Since the seminal paper by Kraft and Kraft [20], the causal relationship between energy consumption and income has attracted immense attention from both researchers and policymakers. The global energy landscape is experiencing deep transformation. Overall, the global energy demand continues to increase, albeit at varying rates at the regional level. Demand in the countries of the European Union, the United States, and other industrialized countries is either stabilizing or decreasing, whereas demand in other countries, namely China, India, and other countries in Asia, is displaying a sharp increase, and this is also happening in MENA region countries. This region, and the abundance of fossil fuel within it, has drawn the roadmap of the global energy market. At the same time, the increment in population, developments in industrial infrastructure (mainly in the steel, aluminum, and petrochemical industries), climate change, global warming, desertification phenomena, water desalination, and air conditioning have increased energy consumption. This increases billing fees, which is expected to put pressure on government budgets and reduce the hydrocarbon export potential, thereby resulting in a loss of foreign exchange revenues.

It is clearly the case that the MENA region is adopting a leadership role in the oil market and has more than 50% of the total proven oil reserves in the world (879 billion barrels of oil) [21], but the energy demand (for oil in particular) is increasing. Some countries, such as Indonesia, produce oil, but not enough to meet their growing energy demands. They will therefore have to turn increasingly towards the MENA countries to meet their needs. Already in 2012, the import share from the MENA region to the Asia-Pacific was 65 per cent. Asia consumed 53 per cent of total Middle East production in 2014 and oil consumption grew by a below-average 0.9 million barrels per day (barrel/day) [22,23]. All of this tends to place MENA region countries in a critical situation, where both the global oil market and energy consumption are increasing. GDP and oil price are the control variables of energy consumption in the region, specifying the value and the capacity of financial development. Energy consumption behaves negatively in response to oil price fluctuations. In this case, renewable energy is the only way for MENA energy consumption to be less dependent on oil price fluctuations, and this is why this research concentrates on illustrating the impact of solar and waste (if waste is considered a renewable source of energy) on the entire economic system. At present, oil and gas are the main energy sources in the Middle East [24]. It is important to note here that energy consumption rises with increases in income, and this explains why the GCC have high rates of consumption. However, economic growth can increase energy consumption by (i) encouraging consumers to borrow money to buy big-ticket items, (ii) allowing cheaper and easier access to financial capital, which can be used to expand existing businesses or launch new projects, (iii) attracting foreign direct investment (FDI) inflows, and (iv) bolstering consumer and business confidence, which increases economic activity and the demand for energy, or it may lead to a decrease in energy demand by promoting the renewable energy sector and providing easier and less costly access to innovative technology and environmentally friendly projects.

As indicated in Figure 3, oil exporters have the highest rate of energy consumption, with the exception of Iraq and Libya due to political issues. As noted previously, high income (GDP), air conditioning usage, and growing water desalination capacity have led to a high energy demand.

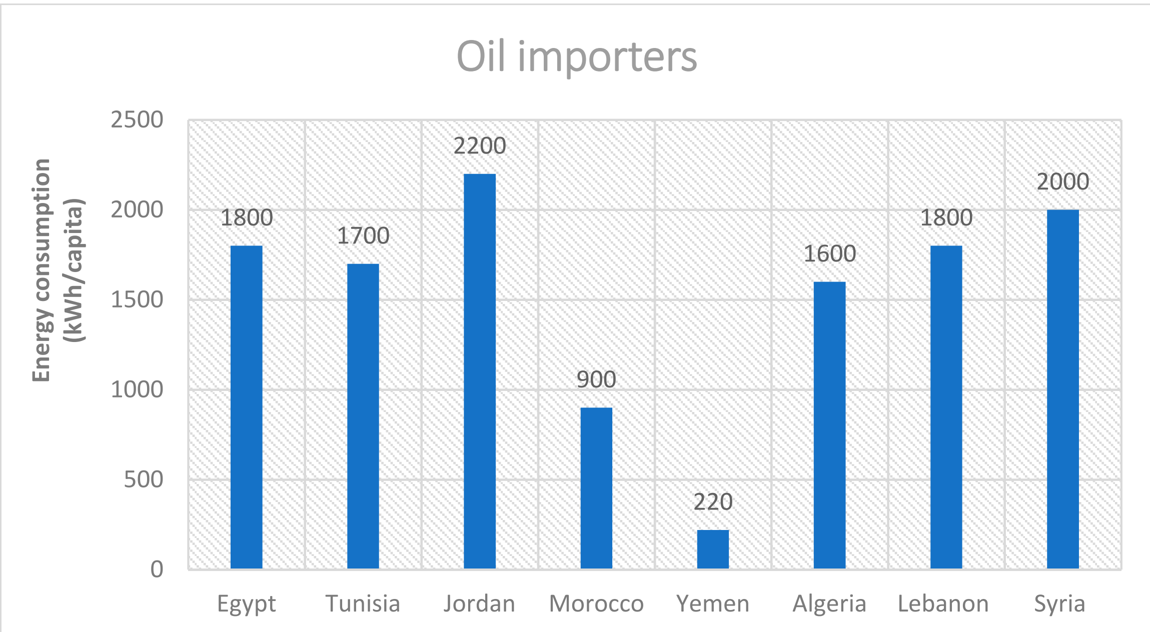

Figure 3. *Cont.*

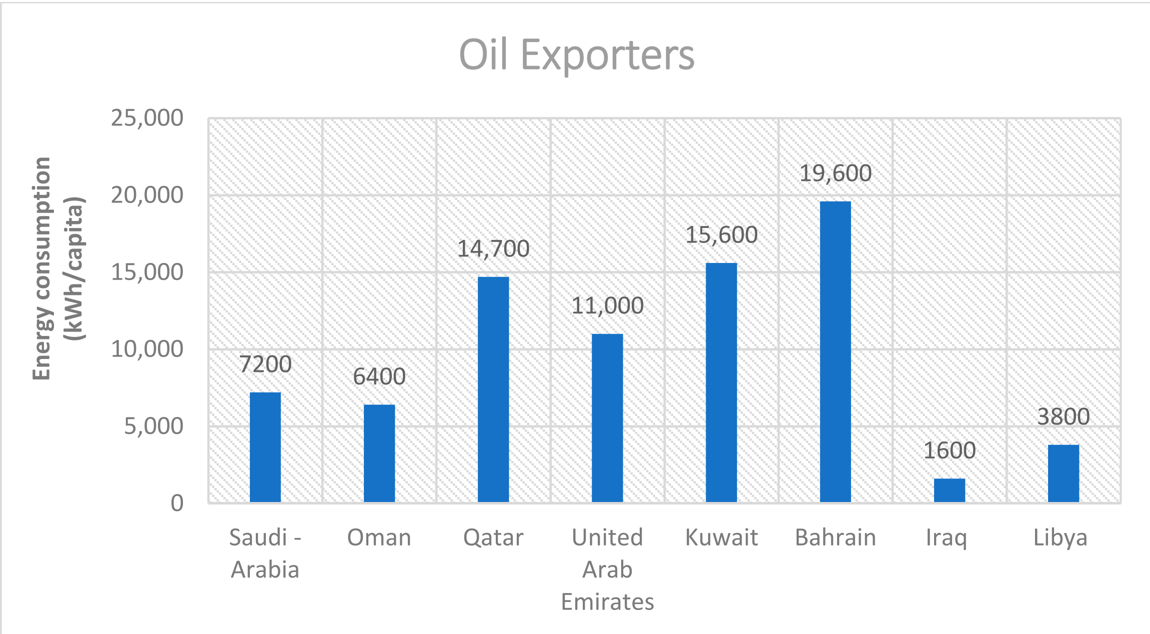

Figure 3. Energy consumption (kWh/capita) for MENA region countries; data adapted from [7,9,25].

4. Higher Energy Consumption Than the Global Average and Dependency on Fossil Fuel

The MENA region as a whole has doubled its share of the world primary energy demand, from 4 percent (370 million t of oil equivalent (mtoe)) in 1990 to 8 percent (1084 mtoe) in 2015. Moreover, the electricity demand increased by around 6 percent on average per annum in the MENA countries during the 1990–2015 period, compared with a world average growth rate of 2.9 percent [24]. By sub-region, most of the growth has been observed in the Gulf Cooperation Council (GCC) countries, as well as in Iran. For instance, Qatar and the Emirates witnessed the fastest growth in energy demand. By comparison, in 2015, two countries, Saudi Arabia and Iran, accounted for 42 per cent of the total primary energy demand (TPED) in the region, followed by Turkey (12 per cent), Egypt (7 per cent), and Algeria (6 per cent), with the rest accounting for the remaining 23 per cent.

On a per capita basis, electricity consumption rates vary meaningfully across the region. Some countries have the highest per capita rates in the world; for instance, Bahrain's consumption rate (20.1 megawatt-hour, MWh) is more than double the average rate for Organization for Economic Cooperation and Development (OECD) countries and six times higher than the world average. Qatar, Kuwait, the UAE, and Saudi Arabia also have consumption rates above the average for OECD countries. The demand for electricity in the region is expected to increase, primarily due to economic development and population growth, combined with increasing needs for water desalination and air conditioning [21,26].

The structure of energy distribution in the region depends heavily on fossil fuels for energy supply and domestic consumption, particularly oil (45%) and natural gas (47%), with a minor share belonging to coal (5%). The region also has the greatest untapped potential for renewable energy in the world, as only 1% of the region's primary energy mix is supplied by renewable energy, with the rest coming from hydropower. Notably, nuclear energy is non-existent in the region's energy mix, but the political decision to invest in nuclear energy remains an option for the future. The UAE and Turkey are advancing their nuclear programs, with the Barakah and Mersin plants under development. Saudi Arabia, Egypt, and Jordan also have plans to introduce nuclear power into their energy mix, while others (i.e., Algeria, Morocco and Tunisia) are in a more exploratory phase [21,27,28]. For the past fifty years, the MENA region has played a substantial role in the global energy dynamic. It accounted for 16% of the world's total energy production in 2014 (half of which is exported). Energy production increased by 2.4% per annum on average between 1990 and 2014. The region accounted for 37% of crude oil production and 22% of the gas supply globally in 2016, leading to a rapid increment in energy consumption internally, as a result of which the energy demand should increase by more than 5% with annual inflation [29]. As noted previously, this situation is likely to increase stress on fossil fuel usage, cause net energy exporters to use their fuel supplies inefficiently, and ultimately strain government finances. On the other hand, it has challenged net energy importers to face the reality of volatile energy prices that threaten their energy security. Consequently, this situation is driving the need for suitable energy strategies and effective policies for sustainable energy development in the region and the need for such research ideas to become applicable projects in reality.

5. Renewable Energy Roadmap

The renewable energy sector in the Middle East and North Africa (MENA) region is growing rapidly, with a diverse range of countries declaring projects and policies to bind the region's abundance of renewable energy resources for economic growth and energy security enhancement. While capacity additions and investment remain below those of other regions, recent years have seen a groundswell of government and commercial interest. For instance, the installed capacity of renewable energy for the whole region was 12 GWe in 2013 and is planned to increase to 80 GWe in 2030. Moreover, renewable energy shares are currently relatively low to non-existent among many of the participant countries, with Jordan being a notable exception given its relatively high share of installed capacity [30]. This is one of the reasons that Jordan was taken as a case study for this research. Over the past five years, renewable energy has shown striking gains in the Gulf Cooperation Council (GCC) countries, Morocco, Jordan, and Egypt. Although it is a relatively recent entrant to the region's energy landscape, it holds immense potential to cut fuel costs, reduce carbon emissions, conserve water, and create jobs. GCC decision makers aim to reduce the risks of dependence on oil and gas revenues, including fluctuating oil prices and changes in global market dynamics. Currently, the Emirates hosts close to 79% of the installed solar PV and 50% of the CSP capacity, respectively, in the GCC. Alongside this, they recognize the need to plan for the post-oil era, when the demand for fossil fuels might subside regardless of supply outlooks [31]. At the same time, Jordan has shown notable progress and the contribution of renewables to Jordan's electricity mix has grown impressively in recent years, rising from only 1% in 2014 to 13% in 2019. Renewable energy systems feeding into the national power grid reached 1558 megawatts (MW) by 2019 and have since swelled to some 2200 MW, or 20% of the overall electricity mix [32]. The global trend of renewable energy is largely dependent on solar and wind energy (as variable renewable energy sources) to verify the turning point and shift to clean energy sources. This is supported by the available data in [33] (p. 52), where the capacity of renewables increased from 40 GWe and 50 GWe in 2014 to 130 GWe and 90 GWe in 2020 for solar and wind, respectively. By contrast, hydropower, bio-power, geothermal, and ocean power decreased from 40 GWe to 20 GWe. The same trend is redundant in MENA region countries.

As mentioned previously, different factors have increased the need to merge renewable energy systems within the power or infrastructure of countries in the region. Nevertheless, all the land in the region is highly recognized as having abundant sources of renewable energy—specifically, solar energy (radiation) and wind [31].

Several studies have published data about the current situation regarding renewable energy capacities and the progress and growth of this sector in the region. The detailed data presented in Figure 4 were updated and collected to give a precise overview of the real situation of renewables and the potential market in the near future.

Figure 4. Installation capacities of renewable energy in MENA region countries; data adapted from [34] and updated from [14,31,32,35].

Morocco was not considered in the figure, but is leading the region in terms of solar (CSP technology) and wind energy. In 2018, Morocco increased its renewables capacity, tripling its solar capacity to 711 MWe and raising its wind capacity by 36% to 1.22 GWe. Since 2007, the installed wind turbine capacity has increased by 25% [35–37].

It is clear that all countries are making an enormous investment in solar technologies (PV and CSP) and, with regard to wind turbine fields, Egypt is taking the lead, with 550 MWe, followed by Iran. Biomass is considered less important in the region, as only three countries are investing in such projects: Qatar, the Emirates, and Israel. It should be noted also that hydropower has a large share in the power sector of the region, especially for those countries with surface water bodies, such as Iraq. Solar technologies have attracted huge interest from the governments and investors in the region, due to its maturity and the massive availability of solar energy reaching this area of the world. It is also worth determining the sale prices, which are stated by the authorities in the region for the renewable resource sector. In this respect, each technology has different parameters in terms of direct costs and operational costs, affecting the evaluation of consumption prices of each kwh coming from multiple sectors (multiple renewable resources). The prices of the power sale of renewable energies as a resource in MENA region countries were adapted from the available data in [34,38], as depicted in Figure 5.

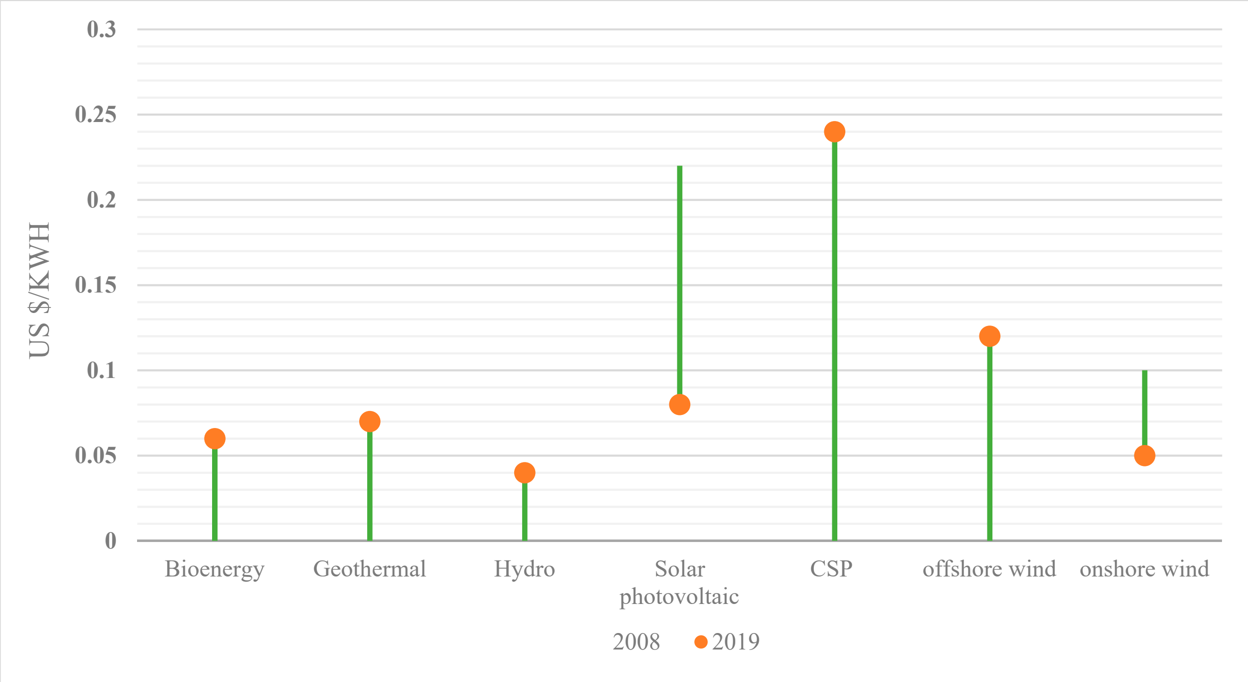

Figure 5. Power sale prices of renewable energy sectors in MENA region.

As shown in Figure 5, the highest cost is related to the CSP system. This contains many basic components that increase the levelized cost of electricity and lead to increased feed-in tariffs. Offshore wind fields also have a high price due to the advanced foundations required to install and maintain these turbines offshore. As expected, solar photovoltaic and wind onshore witnessed a dynamic drop in power sale prices, as investment in these sectors has increased substantially over the last ten years (as mentioned previously).

6. Status of Renewable Energy in Jordan

As the case study for this research, the development of the renewable energy sector in Jordan is highlighted in this section. The total primary energy supply (TPES) grew at an average annual rate of 3% between 2010 and 2017, reaching 10 million t of oil equivalent (mtoe) in 2017. However, in 2018, there was a fall of 3% to 9.7 mtoe due to stagnating consumption across certain end-use sectors. Oil accounted for more than half of the energy supply in 2018, followed by natural gas and electricity. Crude oil and its derivates are predominantly used in the transportation sector, where the fuel demand has grown rapidly amid population growth, increasing urbanization, and greater economic activity [39]. Jordan is facing numerous problems in its energy sector, in addition to the growth of the population and industry, which is already increasing the rate of consumption by default, as it is entirely dependent on imported energy, which reached 99.9% in 2014 but fell to 92% in 2018. This reduction can be attributed to the growth in the contribution of renewable energy in 2018 to 8% (it is expected to reach 31% by 2030) [39]. The growing reliance of the power sector on a single, largely imported fuel has generated concerns with respect to long-term energy security and the affordability of supply. In recognition of these concerns, the government has taken important steps toward the diversification of the energy mix. The Master Strategy of the Energy Sector 2020–2030 aims to increase the share of domestic energy resources in primary energy to 48.5%, primarily through the use of renewable energy and oil shale, so that the primary energy supply will grow from 9.7 mtoe in 2018 to 10.3 mtoe in 2020 and 12.4 mtoe in 2030 [32].

Energy consumption per sector is distributed as follows: households account for nearly half (46%) of the total electricity consumption, while industry is the second-largest consumer, accounting for around a quarter of the total consumption. Among the major industries that account for a considerable share of electricity use are cement, phosphate, and fertilizer. The commercial sector consumes approximately 14% of all electricity [40].

It is extremely important to emphasize that this research matches the strategic plans of the Jordanian government in terms of energy supply and water security. Jordan is one of the most water-scarce countries in the world, so the sector is highly energy-intensive in order to meet its needs for the extraction, transport, and treatment of water. To reduce the energy costs of water pumping, the Ministry of Water and Irrigation aims to improve energy efficiency by reducing specific power consumption for the water supply by 15% by 2025 and raising the share of renewable energy in power consumption to 10% by 2025. As the water demand grows and more energy-intensive solutions are needed (e.g., Red Sea–Dead Sea water conveyance project, desalination), coupling an affordable renewable energy supply with water infrastructure will become crucial, as is increasingly evident across the Middle East [39]. Hence, this is the rationale for the current research.

To determine the effect of global oil prices on the energy sector and economic situation in Jordan, it is important to note that Jordan's oil importer country, the National Electric Power Company (NEPCO), has accumulated substantial debt (~18% of national debt) due to high crude oil prices between 2011 and 2014 and imports of expensive fuel alternatives as a result of disruptions in the supply of natural gas [41]. Despite cross-subsidies from industry, large consumers are used to tariffs for low-income households being maintained at affordable levels. The average tariff has almost reached cost recovery but is still insufficient to cover the debt of the state-owned NEPCO. In its 2018 Annual Report, NEPCO reported annual losses of JOD 106 million (~USD 150 million) [42]. This led to the establishment of a new tax law called the Fuel Price Increase. This is an additional expense for all electricity consumers consuming above 300 kilowatt-hours (kWh)/month (see Figure 6).

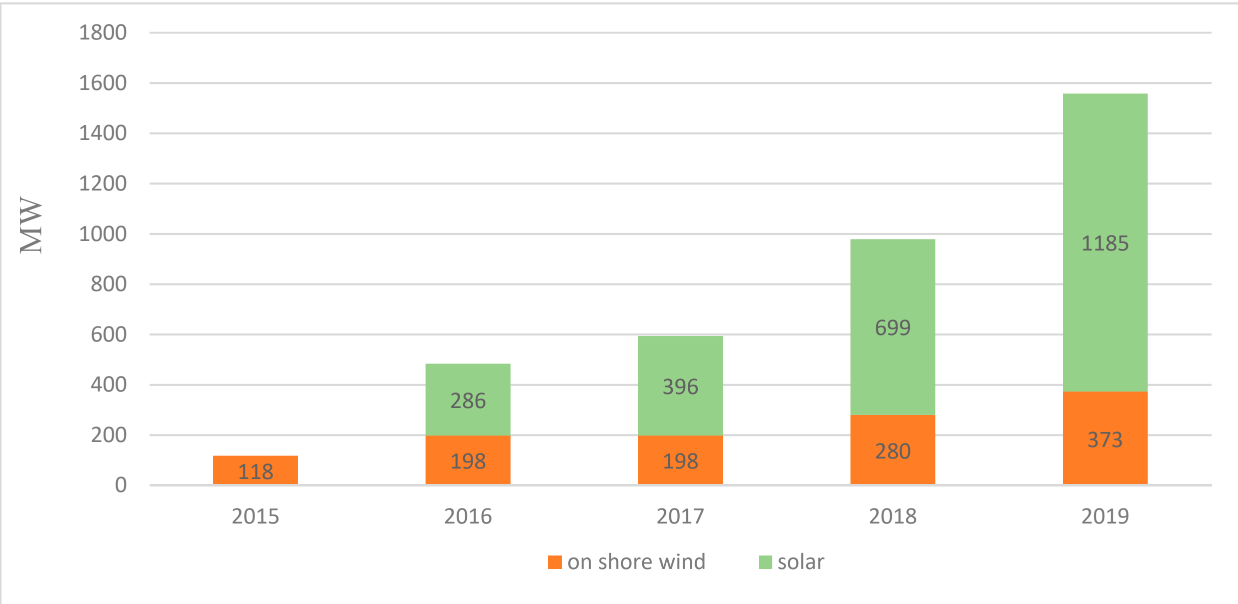

Figure 6. Renewable energy capacity from 2015 to 2019 in Jordan; data adapted from [32].

7. Current Waste Management Situation

The waste management situation in almost all countries of the MENA region is characterized by deficiencies in waste management legislation and poor planning. Many countries lack legislative frameworks and regulations to deal with waste. Insufficient funds, an absence of strategic waste management plans, a lack of coordination among stakeholders, a shortage of skilled manpower, and deficiencies in technical and operational decision-making are some of the hurdles experienced in implementing an integrated waste management strategy. Another critical issue is the lack of awareness and public apathy toward waste reduction, source segregation, and waste management. Waste management is limited to collection and transport. In some countries of the region, the toxic waste from industries and hospitals is mixed with the household waste that is collected, transported, and deposited [43]. These types of findings occur frequently in the literature, which has been helpful in highlighting the issues, recognizing the main challenges and problems in the waste system, and trying find solutions in line with the current situation and existing infrastructure. Fundamentally, the most important issue in the region is that waste is treated as "waste" rather than as a "resource". This concept is not only found among laypeople but also specialists such as decision makers in municipalities and Ministries of the Environment. Moreover, in countries that have achieved remarkable progress in the field of waste management, the issue has now begun to shift from an integrated system for waste management to a circular economy and sustainability, by making waste an essential component of the elements of the economy and economic growth. For example, in Germany, waste management is a multibillion-euro economy, with an annual turnover of EUR 70 billion [44]. To attain a sustainable and circular economy in the MENA region, the need to decouple resource consumption from economic growth is critical. There are two levels that should be taken into consideration. First, the concept or the term "waste management" must be transformed to "waste and resource flow management" [45]. Second, the waste management system must not be treated as a system but as a comprehensive industrial sector. With these concepts, a new methodology will emerge that demonstrates how waste is a source of materials for the production of energy and goods.

7.1. Quantities

The amount of MSW generated differs substantially from place to place, city or countryside, and the rate of waste generation is a function of the annual income, lifestyle, and awareness of society. Several works have detailed the amount of waste generated in different countries in the region. For instance, Hemidat [46], Chaabane [47], Hadidi et al. [48], and Alsabbagh [49] specified the amount of waste generation in Jordan, Tunisia, Saudi Arabia, Bahrain, and Gulf countries, respectively, while Elnass [50], Abdallahet al. [7], and the World Bank Report [25] specified the amount of MSW generation in more than 18 countries in the region. Overall, the rate of MSW generation ranged from 0.6 kg/capita/day in some rural areas in the region, such as in Egypt and Jordan, to 3.1 kg/capita/day in urbanized cities of the region, such as those in GCC countries. However, the normal average rate was also specified, which was stated as being around 1–1.5 kg/capita/day [12].

7.2. Characterization

To verify the optimum treatment for the waste generated daily, the characterization and composition of MSW is the key factor that should be taken into consideration. However, a large difference exists worldwide between the MSW generated in developed and developing countries in terms of waste composition. The municipal solid waste generated in developed countries is mainly inorganic in nature (around 34% is organic waste, as in Germany [51]), whereas organic content dominates the waste in developing countries. The proportion of organic content in developing countries is almost three times higher than that in developed countries, followed by recyclable materials such as plastics and paper. Even though the volume of waste generated in developing countries is much lower than in developed countries, the waste is denser and has a very high humidity content [47]. Several parameters governing and controlling the nature and composition of MSW, current activities in a region, geographical and climatic conditions, and population all influence the nature and the composition of waste [52]. The main aspect of the MSW composition in the MENA region is the high portion of organic fractions, which constitutes approximately 50–60% of the waste composition. This means that MSW holds a large portion of water in its content [12,53], as indicated in Table 2.

Table 2. Waste composition in the Middle East and North Africa (MENA) region, 2019 [7,49].

	Waste Fractions (%)							
Country	*Paper*	*Plastic*	*Glass*	*Wood*	*Textiles*	*Organic*	*Metal*	*Others*
Egypt	6.3	11.8	1.2	0.1	2.3	66	4	8.3
Tunisia	11	7	2	0	3	68	4	5
Jordan	11	16.8	2.1	0	0	63	2.1	5
Iraq	1	1	1.6	0	0	63	1.1	32.3
Algeria	9	12	1	0	0	62	2	14
Lebanon	18	8	8	0	0	58	2.4	5.6
Libya	5.5	7.5	3.1	2.5	1.3	70.1	4.3	5.7
Syria	4	7	4	0	0	62	6	17
Saudi Arabia	27	5	5	7	5	38	6	7
Oman	15	25	5	1	5	30	0	19
Qatar	20	25	4	4	4	35	0	8
United Arab Emirates	20	25	4	4	4	35	0	8
Kuwait	20	15	4	4	4	45	0	8
Bahrain	10	30	3	3	5	38	0	11
Yemen	7	10	1	0	0	65	6	11
Morocco	10	10	3	0	0	65	4	8

As noted previously, the variation in waste composition is due to governing parameters such as geographical and climatic conditions, population growth, economic income levels, and socio-cultural properties. The waste composition in the Gulf region differs from that of other countries in the region, as can be seen in Table 2. For instance, the proportion of organic fractions ranges from 30% for Oman to 45% for Kuwait. This reveals the effect of GDP on waste generation behavior—high-income countries (such as Gulf countries) tend to consume more fast food meals than other countries in the region with a low income, in which people tend to cook food in their houses, which is more economic. Thus, the Gulf countries generate a higher rate of package waste and a lower rate of organic waste (food residue).

7.3. Disposal of Waste

In the MENA region, 90–95% of municipal waste goes to landfill, without any pretreatment process [54]. The actual situation is that all countries share the same characterization and the same final treatment processes. The main cause of this similarity in disposal is that all MENA countries face the same challenges and share the same institutional concept of dealing with waste as rubbish to be disposed of, rather than as a material flow source that needs to be harvested and exploited to shift from a linear economy to a circular one. Separation at the source is the major driver of the waste management system, which is not applied in the waste sector in the region. This increases the complexity of applying a treatment methodology and diversifying treatment streams. It is important to note here that the UAE has a 27% recovery rate of the materials, as they were the first country in the region to erect recycling stations to recover recyclable fractions from waste, while Lebanon has a 23% recovery rate [50], as shown in Table 3.

In Europe, incinerators treat around 25% of the daily generated waste. The same scenario was applied for MENA region countries, and to illustrate the relationship between municipal waste and the energy sector, Equation (1) was used. The following assumptions were made for the equation:

- 25% of municipal waste is subjected to incineration;
- 40% is the total dry matter of waste;
- Annual operation hours of the waste incineration plant are 7200 [12];
- Efficiency of energy conversion is 30% [7];
- A Lower Heat Value (LHV) of 7 MJ/kg was taken as a constant annual average value [12].

$$ERP = W_{dry} \times LHV \times \eta, \quad (1)$$

where ERP is the energy recovery potential (kWh), W_{dry} is the dry weight of waste (kg), LHV is the Lower Heat Value of waste (MJ/kg), and η is the efficiency of energy conversion within incinerators. The results are presented in Table 4. The amount of energy harvested from waste can be distributed to cover some of the energy requirements of the population, which depends on the rate of energy consumption/capita, as indicated in Figure 3.

Table 3. Treatment streams of MSW in MENA region countries; data adapted from [7,25,49,50,55–57].

Country	Open Dump (%)	Controlled Landfill (%)	Sanitary Landfill (%)	Recycling (%)	Composting (%)	Anaerobic Digestion (%)	Incineration (%)
Algeria		2	89	8	1		
Bahrain		92		8			In plan phase, to accommodate 390 Kilo ton/year
Egypt	80	5		10	5		
Iraq	100	no available data	no available data	no available data	no available data		
Jordan	45	48		7			
Kuwait	100						In plan phase, to accommodate 1195 Kilo ton/year
Lebanon	29	48		8	15		
Morocco	54		37	8	1		
Oman	100						In plan phase, to accommodate 390 Kilo ton/year by 2023
Qatar		90		3			
Saudi Arabia		85		15			Ambitious target of 3 GW for WtE facilities in 2030
Syria	80	16		2.5	1.5		
Tunisia	21	70		4	5		
Emirates	62	9		20	9		In plan phase, there are 4 projects in 4 cities with 2525 Kilo ton/year
Gaza	67	32		0.5	0.5		
Yemen	68	24	no available data	8	no available data		

As Table 4 shows, in the case of Egypt, which has the highest population in the region, the energy generated (for the considered scenario) is around 1.4 million MWh, which covers the energy consumption of 792,545 capita. Conversely, in the case of Saudi Arabia, the amount of energy recovered from waste is around 1 million MWh, which can be supplied to 144,773 capita. Overall, the energy distribution/capita depends entirely on the energy consumption rate (see Figure 3), where the energy consumption is 1800 kWh/capita and 7200 kWh/capita for Egypt and Saudi Arabia, respectively. Furthermore, the daily waste generation rate depends on the GDP of the country; for example, Iraq generates around 12,763,673 Ton/year and its population is around 40 million capita, while Saudi Arabia generates 21,740,861 Ton/year of waste and its population is around 33 million capita. This is attributed to the high GDP of Saudi Arabia, emphasizing the importance of distinguishing between oil exporters and oil importers in the region, as the difference in GDP directly affects the waste generation rate and energy consumption.

The conclusion drawn here is that there are two main factors governing the waste generation rate and energy distribution: GDP and energy consumption/capita.

Table 4. Possible energy recovery from waste by applying Equation (1).

Country	Total Amount of Waste/Year	25% Is Sent to Waste Incineration Plant	40% Dry Matter	Energy Produced by Incineration According to the Equation Below (Mwe)	MWh (7200 is the Operational Hours/Year of the Plant)	Number of Persons Receiving Their Energy from Waste Incineration
Egypt	29,754,405	7,438,601	2,975,440	198.14	1,426,581	792,545
Tunisia	2,522,045	630,511	252,204	16.79	120,919	71,129
Jordan	3,435,588	858,897	343,558	22.88	164,720	74,872
Iraq	12,763,673	3,190,918	1,276,367	84.99	611,956	382,473
Algeria	13,684,484	3,421,121	1,368,448	91.13	656,105	410,065
Lebanon	1,335,916	333,979	133,591	8.90	64,050	35,583
Libya	1,898,354	474,588	189,835	12.64	91,016	23,951
Syria	3,550,403	887,600	355,040	23.64	170,224	85,112
Saudi Arabia	21,740,861	5,435,215	2,174,086	144.77	1,042,370	144,773
Oman	2,525,749	631,437	252,574	16.82	121,097	18,921
Qatar	1,552,864	388,216	155,286	10.34	74,452	5,064
United Arab Emirates	6,019,665	1,504,916	601,966	40.09	288,614	26,237
Kuwait	1,596,765	399,191	159,676	10.63	76,557	4907
Bahrain	1,421,740	355,435	142,174	9.47	68,165	3477
Yemen	6,278,123	1,569,530	627,812	41.81	301,005	1,368,208
Morocco	10,019,72	2,504,931	1,001,972	66.72	480,397	533,775

8. Land Requirements for Landfill

The landfill area requirements for waste disposal depend on several parameters, including waste mass, waste/cover ratio, compacted waste density, settlement, side slope, and cell dimensions. The waste density after compaction is typically in the range of 500–700 kg/m^3, while the waste/cover ratio is between 4:1 and 10:1 [58]. Moreover, the waste settlement is typically in the range of 0–50%, while landfill site facilities require 5–20% of the disposal area. Conversely, WTE facilities require a land area of roughly 1 ha for every 100,000 t of waste annual capacity. For the incineration process, the waste mass is reduced by 95%, and landfill volume by around 90%. The ash resulting from the incineration plant is deposited in the landfill. As noted previously, AD results in a mass reduction in the treated waste by approximately 50–60%. The remaining digestate is typically used as a soil conditioner and does not require landfilling area, but, as noted earlier, the biochemical treatment deals with only the organic fraction, not with all waste stream fractions [7].

9. Financing and Economic Aspects

As concluded from the preceding sections, the waste management system in the MENA region exploits the financial allocations of governments with respect to collection, transportation, and the cost of landfilling or dumping. Collection varies by department and depends on financial, logistic, and infrastructure resources. Two types of collection are currently used: free access to waste tanks deposited in the street and direct collection from the population (informal sector). According to the practical experience of waste management, the material flow department of Rostock University, and available information in the literature, MENA countries exhibit almost the same patterns in terms of financing aspects, which are as follows: inappropriate collection equipment, no controlled landfills, no professionalism management, no strategic plan, and a lack of funds to improve the sector.

In Saudi Arabia: Saudi Arabia generates approximately 15 million t of solid waste per annum. Nearly half of this waste is generated in the three largest cities, Riyadh, Jeddah, and Dammam. Solid waste generation is expected to reach approximately 22 million t by the year 2030. The municipal solid waste (MSW) throughout Saudi Arabia has a high organic content of nearly 40% or more [59]. Because it is common in MENA region countries, MSW collected from individual bins or community bins in Saudi Arabia is then disposed of in landfills or dump sites. The waste sector is characterized by a lack of waste treatment, such as sorting and recycling, with an incremental intention to use waste as a source of income. In 2017, SAR (Saudi Riyals) 54 billion, equal to around USD 14 billion, was allocated out of the national budget by the government to waste services, including water drainage and landfilling [60]. The Saudi government realizes and is very aware of the problems of the waste sector and the urgent need to find sustainable solutions. In 2011, the budget for the waste sector was around SAR 29 billion (USD 7 billion); notably, the increase in financial allocations matches the increment and changes in lifestyle and population growth [60]. According to the data, the cost of each ton of waste (collection, transportation, and treatment in landfilling with water drainage handling) is around USD 930. It should be noted here that the Ministry of Economic and Planning in Saudi Arabia asserts that 35% of waste generated in the country is recycled [60].

In Morocco: Collection varies between 75 and 100% of the available solid waste (SW). Due to the lack of appropriate collection, treatment, and disposal infrastructure, nearly all hazardous waste produced by the industrial sector is disposed of in uncontrolled dumps, municipal landfills, on nearby land, in abandoned quarries, or along rivers, without any treatment or control. The lack of financial infrastructure in this sector is responsible for this deficit in collection. Consequently, the government has set out a national plan for domestic waste, which was launched in 2008 to achieve multiple goals, one of which was to achieve 90% collection by 2020 and 100% by 2030. The cost of the program was evaluated at USD 4 billion over a period of 15 years. The program is a collective contribution involving communes (73%), taxes (11%), State (9%), and others (7%) [61]. This means that for each year (through the 15th year of the plan starting from 2008), there will be around USD 260 million for the waste sector, 73% of which will be taken for the collection process. Because Morocco is a country of 34 million inhabitants, there will be around 34,000 t/day of MSW (calculated according to the available data, where average MSW generation /capita/day is 1 kg) [12]. Thus, it can be concluded that the cost of collection/ton is around USD 15.7, excluding treatment costs in landfills or any other streams of treatment.

In Tunisia: In terms of enacting laws, Tunisia was one of the first countries in the region to enact waste management laws and force the producer to take responsibility through assertions such as "the polluter pays" and "the producer recovers", which were explicitly stated in the framework of Law 96-41 of 10 June 1996 [47]. Unfortunately, in reality, these laws are not applied as there is no specific solid waste management cost recovery system in Tunisia. Municipalities use local taxes to finance the direct operating costs of waste collection and disposal. These taxes recover part of this cost, and the shortfall is compensated for by other local municipal revenues. For local communities, the primary mechanism in place is a tax to be paid by buildings, which corresponds to the cost recovery of cleaning services and housekeeping. This tax is calculated based on 2% of the reference rate per square meter multiplied by the surface area of the building [61]. In urban areas, the collection and transport of waste can be self-funded by urban area funds. In rural, non-communed areas, financial transfer and state donation cover a substantial proportion of the cost of services related to the collection and transport of solid waste, organized by the regional committees and the rural councils.

The recovery rate is limited to 30% [61], which is related to collection and transportation. ANGed is responsible for implementing the program of the realization and exploitation of controlled landfills and transfer centers. Infrastructure financing is ensured by eco-taxes and the support of technical and financial partners. Urban areas contribute to the cost of waste transfer to the landfill at a rate of only 20% [47]. Thus, the remaining 50% of the cost can be covered with a loan at a preferential rate to be paid over 10 years [61].

In Egypt: Average collection coverage ranges from 60% to 85%. Door-to-door waste collection is mainly concentrated in high-income areas in cities, while low-income areas mainly depend on the services provided by the municipalities. Environmental problems, including those relating to SWM, have usually been tackled using command and control (CAC) regulations, which monitor performance by proposing specific legislation and standards that must be achieved and enforce obedience through the use of penalties and fines [62]. Egypt is one of the most densely populated countries in the region, with around 100 million inhabitants, and in Cairo (main city) alone, more than 20 thousand t of MSW are generated each day by the 20 million residents who live there. To illustrate the power of the waste sector if waste is considered as a source instead of garbage that needs to be disposed of, around USD 12,094,191 (EGP (Egyptian pounds) 190 million) are verified yearly by the informal sector through the collection of around 2.5 million t of waste per annum and the recycling of more than 80% of this [63]. Several studies have identified the chronic problems of the waste sector in Egypt [64–67], highlighting insufficient financial resources as the main challenge impeding adequate services of SWM systems governed by municipalities; for example, a large proportion of people in the Assiut village are participating in private collection models and paying an amount ranging from 15 to 25 EGP/month (0.95–1.6 USD/month) [62]. This amount of money is akin to incentives/services coming from society to support the waste sector. However, cost recovery in the waste sector in Egypt is around EGP 125 (USD 8/ton) and the corresponding cost for disposal is EGP 100 (USD 6.3/ton). Notably, the revenue from the waste collection fees does not cover the expenses needed for a sustainable waste management system. The gap between the available/allocated funding and the actual requirements of the service is in-creasing; adapting additional economic instruments such as waste charges based on the quantity of waste generated, a deposit–refund system, advanced recycling fees, and landfill taxes would improve the cost of the recovery system.

In Jordan: Cost recovery and the fees collected are extremely low, covering only 60% of the costs in the Greater Amman municipality and no more than 30% in the others. The funding system for waste management is primarily characterized by the absence of financial incentives and effective cost recovery mechanisms. The fees for managing waste are generally charged via the electricity bill. The cost recovery is exceptionally low. Municipalities are responsible for financing waste management infrastructure and systems. The MoMA offers low-interest loans to finance municipal activities, including waste management. International grants also play a significant role in financing waste management activities. Fees recovered depend on whether the producer in Jordan is residential, industrial, or commercial, and are as follows [46]:

- A fixed annual lump-sum fee (JOD 20 per household) that is paid in monthly instalments plus JOD 0.005 per KWh (for every KWh above 200 KWh consumption per month), levied with the monthly electricity bill and applicable to households in the Amman municipality;
- A fixed annual lump-sum fee (JOD 24, 15, or 8 per household depending on municipality class) that is paid in monthly instalments, levied with the monthly electricity bill, and is applicable to households in all municipalities except Amman;
- For any professional licensee of commercial, institutional, and industrial activities in municipalities including Amman, 20% of the professional license fee is levied annually.

The challenges facing solid waste management in the region can be summarized as follows.

Legally:

- Lack of regulations and systems for solid waste management [64,68];
- Poor enforcement and implementation of laws and regulations.
- Financially:
- Lack of financial resources needed for solid waste management as the available resources are not sufficient to cover the cost of the process.
- Technically:
- Recycling initiatives fail due to poor performance at the local government level;
- Lack of expertise and human skills;

- Lack of adequate equipment, tools, or facilities for successful recycling operations, in addition to poor maintenance;
- Low public awareness of solid waste management issues—this leads to weaknesses in carrying out recycling operations, as well as creating negative practices in dealing with municipal solid waste and weak public participation in solid waste management [64].

Institutional:

- Lack of institutional and administrative systems and weak coordination between different institutions;
- Lack of supervisory processes for solid waste management;
- Lack of coordination between the government and the private sector and a lack of separation between the different stages of the system (collection, disposal, and transfer) [64].

10. Institutional Framework

This section illustrates patterns in the distribution of responsibilities among related governmental institutions (such as Ministries of the Environment, municipalities, etc.), stakeholders, private sectors (investing companies), and NGOs. As noted previously, this ring (institutional framework) in the chain of the waste management system is a fiscal part. Consequently, there needs to be a high level of flexibility and fusion among the partners engaged to serve the sector. Moreover, the relationship between the public institutions represented by the government and the private sector as companies should be recognized with a high rate of coordination within the stream flow of services introduced by waste sector institutions, so that they are sufficient to match and serve the requirements of society.

10.1. In Jordan

Solid waste management in Jordan operates at three levels: central, regional, and local. The Ministries of the Environment (MoE), Municipal Affairs (MoMA), Agriculture (MoA), and Health (MoH) are the official entities at the central level. The MoE sets plans and policies, as well as monitoring their implementation, while the MoMA regulates municipal solid waste management and supervises related services. At the regional level, the Joint Service Council oversees landfill operations and waste disposal [6]. There are 22 JSCs running 24 landfills disposing of MSW, sewage sludge, olive oil, and industrial waste [46].

Additionally, at this level, the MoA and MoH regulate agricultural waste and medical waste management, respectively. Municipalities, with some assistance from private companies, which collect industrial and commercial waste, operate at the local level and are responsible for the collection of solid waste. The Greater Amman Municipality is also a significant stakeholder as it is responsible for more than 50% of the country's waste [6]. On the financial side, MOMA plays a central role by virtue of its administration of municipal affairs. A key responsibility of this ministry is to provide the municipalities with funds to invest in the SWM infrastructure. It is also responsible for the implementation of the legal framework [46]. Figure 7 depicts the distribution of responsibilities for the waste sector in Jordan.

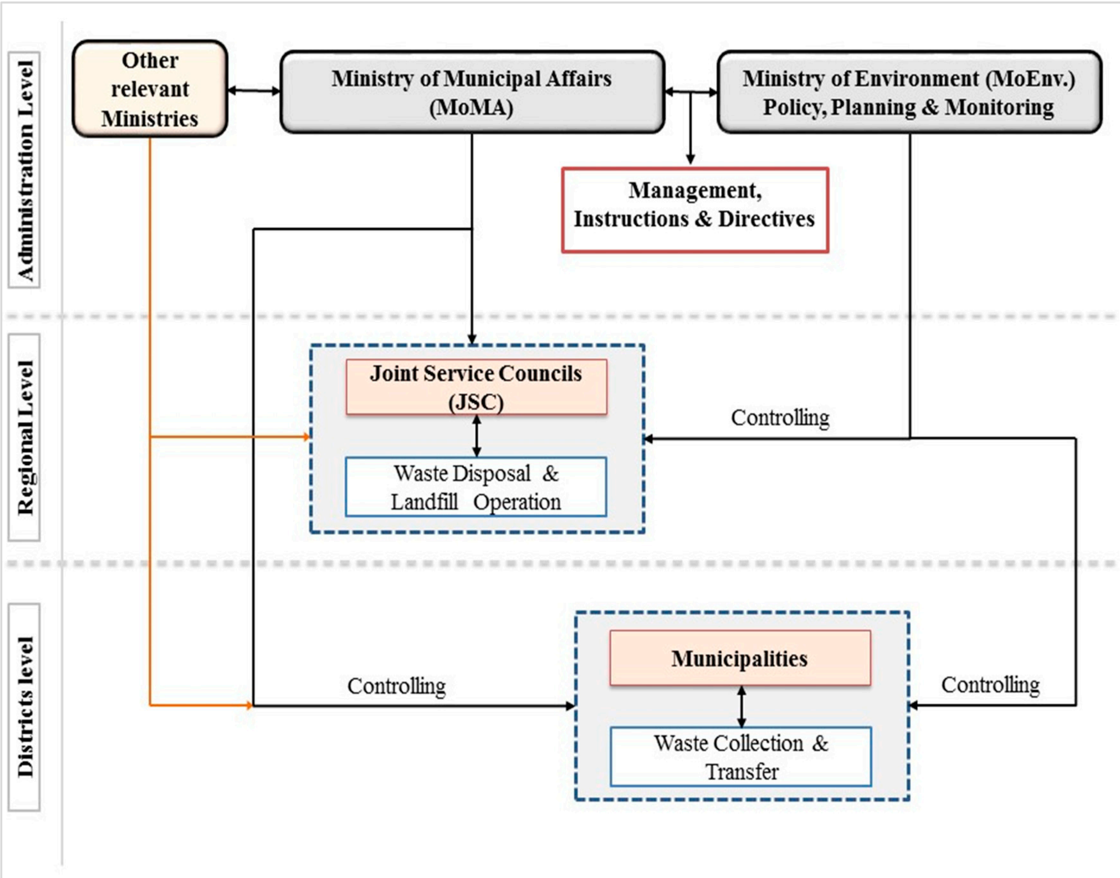

Figure 7. Institutional responsibilities for the waste sector in Jordan, adapted from [69].

Municipalities are fully responsible on a day-to-day basis for SWM operations. The regionalized delivery of municipal services is well established in Jordan under the authority of the legal framework governing the municipal structure and operations. As a consequence, municipalities share waste disposal facilities. In some cases, they also share waste collection systems, although, more commonly, individual municipal units operate their own waste collection systems. Governorates are responsible for monitoring waste disposal sites from a health and safety perspective [70].

10.2. In Egypt

The institutional framework in Egypt and the associated responsibilities are distributed and divided according the stream from which the waste is generated. Thus, green and agricultural waste are the responsibility of the Ministry of Agriculture and Land Reclamation in coordination with the Egyptian Environmental Affairs Agency/Ministry of State for Environmental Affairs. For medical waste treatment using incineration systems, the Ministry of State for Environmental Affairs (MSEA) validated and set maximum limits for emissions from medical waste incineration units and published them in the amended copy of the Executive Regulations of Law 4/1994 to avoid air pollution. However, Egypt generally lacks a specific regulatory and policy framework for industrial waste management. Even though some legislative provisions are in place, enforcement is weak, causing industrial waste to be discarded in open dumpsites, mixed with municipal solid waste. The responsibility for treating and depositing industrial waste in an environmental manner is shared between private sector companies and factories and the public sector, mainly MSEA. The latter is working on increasing and improving technical and scientific capacities in private companies, public industries, and administrations. They are also striving to raise awareness and increase knowledge of resource efficiency and sustainable consumption and production, which are critical in this regard [71,72]. The Egyptian government also encourages NGOs to participate in conducting workshops and seminars in different Egyptian cities, such as Cairo, Alexandria, and the Aswan Governorates. Regarding the related waste stream in this research, the MSW legal and institutional framework of SWM in Egypt is weak and there is an urgent need to modernize the sector. To address this, the Egyptian government established the Inter-Ministerial Committee (IMC) in 2009. In September 2013, a decision was made to establish a new "Integrated Solid Waste Management Sector (ISWMS)" under the Ministry of State for Environmental Affairs (MSEA). The new national authority is tasked with taking responsibility for the solid waste sector in Egypt and to implement the National Solid Waste Management Program (NSWMP). The purpose of the latter is to support the establishment of new and effective policies, legislation, and institutional arrangements for waste management at the national and Governorate level in Egypt, coupled with enhanced professional capacity and an investment pipeline for the implementation of sectoral projects at the regional and local level [73,74]. Figure 8 presents the integrated institutes in Egypt that are playing major roles in waste management activities. As shown, the Ministry of the Environment plays a vital role in accommodating all other players, such as the private sector (companies and factories), Ministry of Agriculture, and MSW units related to the Governorates, motivating them to achieve and move beyond the targets of the NSWMP.

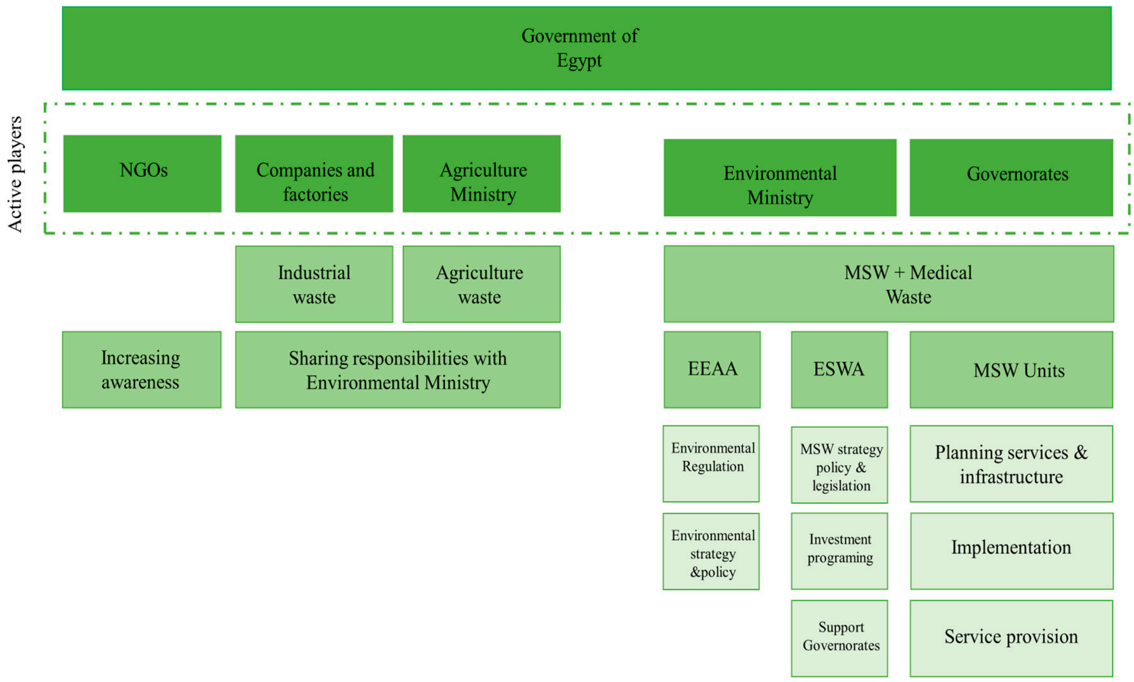

Figure 8. Flow chart of institutional responsibilities in Egypt. EEAA denotes the Egyptian Environmental Affairs Agency; ESWA denotes the Egyptian Solid Waste Management Authority.

10.3. In Tunisia

The main stakeholder in the sector is the National Agency for Waste Management (Agence Nationale de Gestion des Déchets, ANGED), established in 2005, which is responsible for policymaking, implementation, coordination among stakeholders, the provision of technical assistance, and so on. The Ministry of Environment and Sustainable Development (MESD) is the principal policymaker in the sector; it is assisted by the National Agency for Environmental Protection (ANPE), which ensures law implementation and enforcement. Municipal and regional councils are also essential local stakeholders, overseen by the Ministry of the Interior (MoI), yet they lack financial and administrative autonomy. Based on the "polluter pays" principle, the private sector and industrial companies are often involved in waste management collection and disposal [6]. Figure 9 illustrates the institutional responsibilities for the waste management system in Tunisia. Notably, more governmental institutes are involved, according to [47]. The SWM system also indirectly concerns, to a lesser degree, other authorities, such as the Ministry of Industry, Ministry of Trade, and the Ministry of Finance. The Ministry of Finance is also responsible for the development and implementation of financial instruments for SWM and the recovery of related taxes.

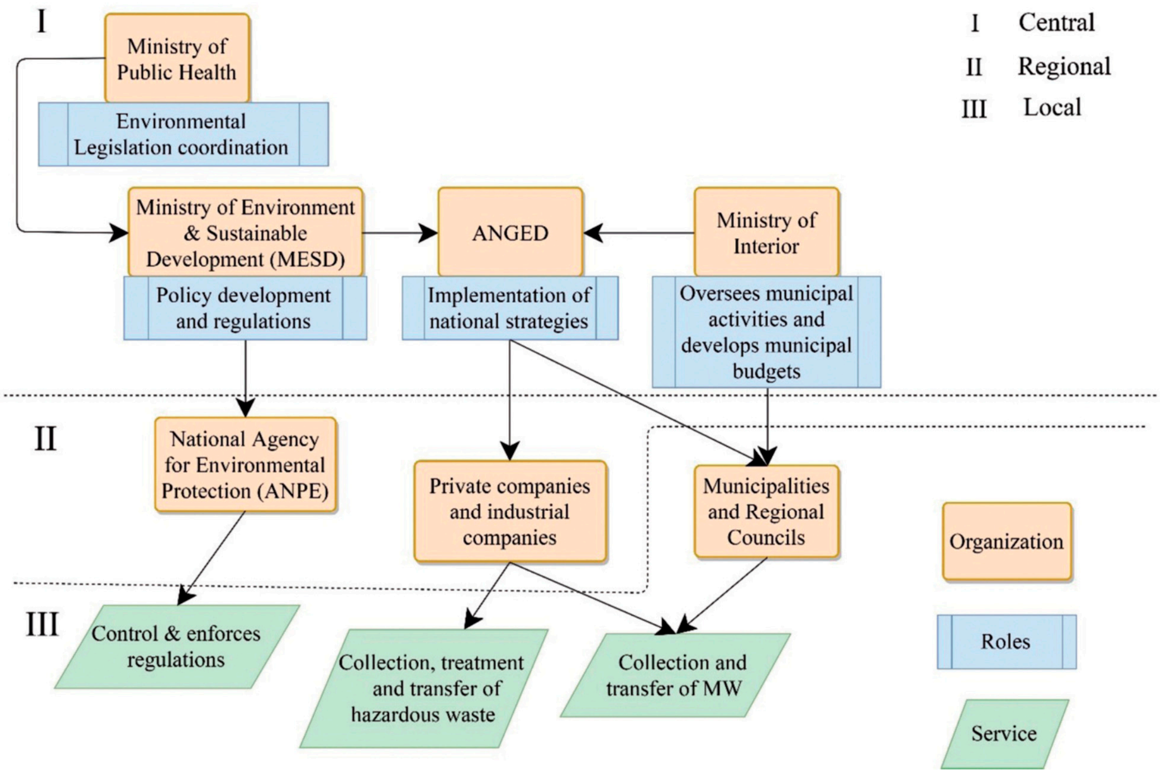

Figure 9. Institutional framework responsibilities of Tunisia, adapted from [6].

As indicated in Figure 9, the Ministries are working on developing regulations and instructions according to their field of work. Municipalities in Tunisia have the primary responsibility for SWM operations (collection, street and beach cleaning, and so on) in the territory. They are responsible for the collection and transportation of mixed waste to the transfer stations, and approximately 350 municipalities serve the country [47]. Conversely, ANGED is responsible for transporting waste from the transfer station to the landfill, the role of waste and leachate treatment, and the degasification of the landfills. It is also responsible for providing the adequate infrastructure (transfer stations, landfills, or other treatment facilities) [47].

According to the reviewed data on the structure of the institutional framework in the three countries of the region, the participation of the private sector is extremely limited and poor. This indicates that there is no major role for investors to carry out business and invest in the waste sector. Furthermore, the large share of governmental institutions increases the financial loads on governments, as such institutions influence the whole system, while there is insufficient cost recovery or taxes to compensate for the expenses caused by the services provided through the management of the waste. Consequently, the waste sector becomes a growing source of expense for governments, which increases debts, especially for countries who are pre-recognized as oil importers, such as Jordan, Tunisia, and Egypt. One of the available solutions to overcome the current challenges presented by waste systems is waste-to-energy (waste incineration), which needs high investment in comparison with other available solutions, such as composting or MBTs. However, at the same time, waste-to-energy is a radical solution for waste. When it is possible for the private sector to invest in the waste sector and governments are fully prepared to integrate this sector into the chain of the waste management system in terms of encouraging laws and regulations, tax exemptions, and long-term contracts to ensure the rights of both sides, many such projects will be established in the region.

11. Suggested Strategies for Dealing with MSW in the MENA Region and Future Research Work

The waste management sector in the MENA region still has a number of deficiencies and barriers that need to be overcome. This sector still places a burden on state budgets, instead of being converted into an investable sector that would have a positive impact on the government budget. Several factors have led to the emergence of this sector as it is now: societal awareness, unwillingness to make decisions (on the part of the decision makers), financial problems, a lack of infrastructure, and landfilling being the major means of treatment. Simple, restricted projects operate on a very small scale and without accurate data in terms of the classification of waste composition and its calorific value.

An integrated strategic plan needs to be devised to deal with the current waste situation. The main treatment streams for the generated waste are recycling, energy recovery (incineration), and landfilling. Notably, landfills should receive inert materials, which constitute around 1–5% of the generated waste after passing through all treatment processes. Of course, this is the optimum case that is applied in developed countries; for the MENA region, the strategic plan can start as follows.

Technical part (as future research work):

- Sorting analysis of the MSW, at least for the main cities.
- Sorting is related to determining the major fractions of the MSW, while sampling must be implemented for each fraction. This means a detailed analysis in terms of water content, volatile content, and ash content for each fraction, rather than focusing on the lump sample, to precisely evaluate the LCV and obtain a precise percentage of water content in the MSW. Furthermore, elementary analysis is required for the combustible fraction.
- Sorting analysis must be performed for six months from January through to July. During this period, numerous parameters will affect the composition of the MSW, particularly the moisture content, where the behavior of the inhabitants tends to change. In addition, the effect of weather conditions will increase the evaporation rate during the summer months.

Practical part:

As a first stage, this can start with 50% treatment (recycling and energy recovery) and 50% landfilling.

- New regulations and laws to support recycling and energy recovery from waste need to be implemented and discussed.
- Increasing the role of the private sector and motivating it to invest in recycling projects in terms of the PPA concept (public private associating), and involving the informal sector. The recycling rate must be increased to reach 30% of total generation.
- The concept of dry and wet containers needs to be activated and implemented, at least for the main cities. This will be the first step towards source separation. This concept expands the treatment possibilities in terms of composting and biogas production as the organic fraction will be pre-separated and prepared.
- The concept of energy recovery from waste needs to be well defined in institutional frameworks, which should be prepared to invest in this. Energy recovery should receive 20% of the generated waste. The European Union is always seeking ways to increase the recycling rate by issuing new laws and regulations. Despite this, around 25–30% of the total MSW generated in Europe is sent for incineration.
- Financing needs to be pre-prepared to build up comprehensive economic revenues for the waste system.

- Unifying the responsibility for decision making and putting in place all stakeholders to activate and discuss the applicable solution.

12. Discussion

Numerous indicators highlight the urgent need for waste-to-energy power plants to be inserted into the waste management system in MENA region countries as an optimum treatment for the aggravating problems of the waste sector. The waste-to-energy sector is promising in the MENA region as massive amounts of waste are generated, the energy demand is escalating, and natural reserves of fossil fuels are being depleted. Further, the nature of the waste is entirely mixed and heterogeneous as there is no separation at the source at all. To facilitate this, immense efforts are required from governmental institutions and society, especially regarding awareness, and a long period of time will be needed to achieve success. However, separation at the source needs multiple streams of treatment, which requires a comprehensive infrastructure to accommodate the outcomes from separation, such as recycling facilities, compost plants/biogas plants, and waste-to-energy plants. The existing challenges highlighted in this paper place additional loads on all stakeholders in the waste sector in the region, the foremost amongst which are financial barriers. The key benefit of incineration (waste-to-energy) lies in reducing the waste volume by 70% and mass by 80% [12]; hence, less landfill disposal space is required [75]. Incineration is one of the most well-established thermochemical technologies and has become an integral part of MSW management strategies worldwide. Most of the energy stored in MSW fractions can be recovered as heat, used in energy production [76]. The most important issue to be addressed is that waste incineration can handle around 65–80% of the energy stored in organic materials. This can be recovered in the form of heat that can be employed in other power-producing facilities based on thermal supplies [77], rendering waste incineration an optimum option to treat and handle the waste in the MENA region. Indeed, MSW in the region is characterized by a high portion of organic material in its content.

Globally, the feasibility of various WTE projects has been well demonstrated in developed countries due to technological advancements, sufficient technical and research data, as well as governmental support. By contrast, developing countries lack the knowledge and data to encourage potential WTE investments, which is why this research presents a comprehensive analysis of the potentiality of the waste incineration set-up in the region, along with a financial analysis. With respect to developing countries, several studies have been conducted for different countries on the viability of WTE technologies within their specific local conditions. Ouda et al. [78] assessed the potential contribution of a WTE facility in meeting the electricity demand in the three main cities in the Western Province of Saudi Arabia and providing an alternative solution to landfills. Three scenarios for WTE utilization were developed: mass burn, mass burn with recycling, and refuse-derived fuel (RDF) with biomethanation. The results reveal good potential to produce approximately 180 MW of electricity based on the incineration scenario; approximately 11.25 MW based on the incineration with recycling scenario; and approximately 87.3 MW based on the RDF with biomethanation scenario. Mohammed et al. [79] assessed two possibilities for financially implementing the waste-to-energy concept in the waste sector in the UAE: anaerobic digestion (AD) or incineration The economics of both strategies were evaluated based on various revenue and cost streams, as well as multiple financial parameters, over a 20-year period. Carbon credits were estimated based on the projected carbon emission reductions from each strategy. Realistic public participation and recovery rates for waste separation and recycling were also applied. The results revealed that the incineration strategy would be profitable, with a net present value of USD 181 million, compared to USD −127 million for the AD strategy. Ouda et al. [80] assessed the potential environmental and economic benefits of a WTE facility in the Gaza strip. The analysis revealed the potential to generate approximately 77.1 megawatts (MW) of electricity based on mass burn technology. Taking the kingdom of Bahrain as a case study, Alsabbagh et al. [49] assessed the positive effect of WTE on climate change mitigation. Cudjoe et al. [81] examined the potentiality of CO_2 emissions from an incineration facility in African countries. However, many research papers investigate the MSW as a source of energy utilizing multiple technologies rather than incineration to recover its energy content [82–84]. Overall, the research field has provided adequate knowledge for the potentiality of waste incineration in the region, but, unfortunately, a waste incineration facility is yet to be erected in the region. It should be noted that UAE will be the first country in the region to establish a large waste incineration facility. A 100 MW facility, one of the world's largest, is under development in Abu Dhabi by the Abu Dhabi National Energy Company PJSC (Taqa), in coordination with the Abu Dhabi Waste Management Center (Tadweer). This will generate enough power for 20,000 households in Abu Dhabi [85]. This article has restructured and provided an updated and reliable database for the waste management sector, energy consumption per capita, and renewable energy progress in the MENA region. According to the data reviewed, GDP plays a significant role in waste generation and the waste composition, as can be seen in Figure 10. For instance, high-income countries have a high generation rate of waste and low organic fractions in terms of waste composition, while low-income countries have a lower generation rate of waste but a high percentage of organic fractions. Such data and related analyses build a roadmap for decision makers and responsible governmental institutions to set up an integrated waste management system. For example, a high share of organic fractions indicates high moisture content and low energy content (LCV)—if this waste was passed into an incinerator, this would provide a pretreatment technique to increase its LCV, such as bio-drying, mixing it with a commercial source of waste, such as paper or cardboard, or increase the bunker capacity. Treatment streams are extremely limited and inefficient, as 90% of the daily generated waste is converted to landfill, while other treatment techniques such as recycling and composting are still in the pilot project phase. The informal sector undertakes the vast majority of the recycling process, by 7–9%. Strategic facilities such as energy recovery plants (incinerators) and biogas production are still in the planning phase and, at present, are only established in Gulf countries.

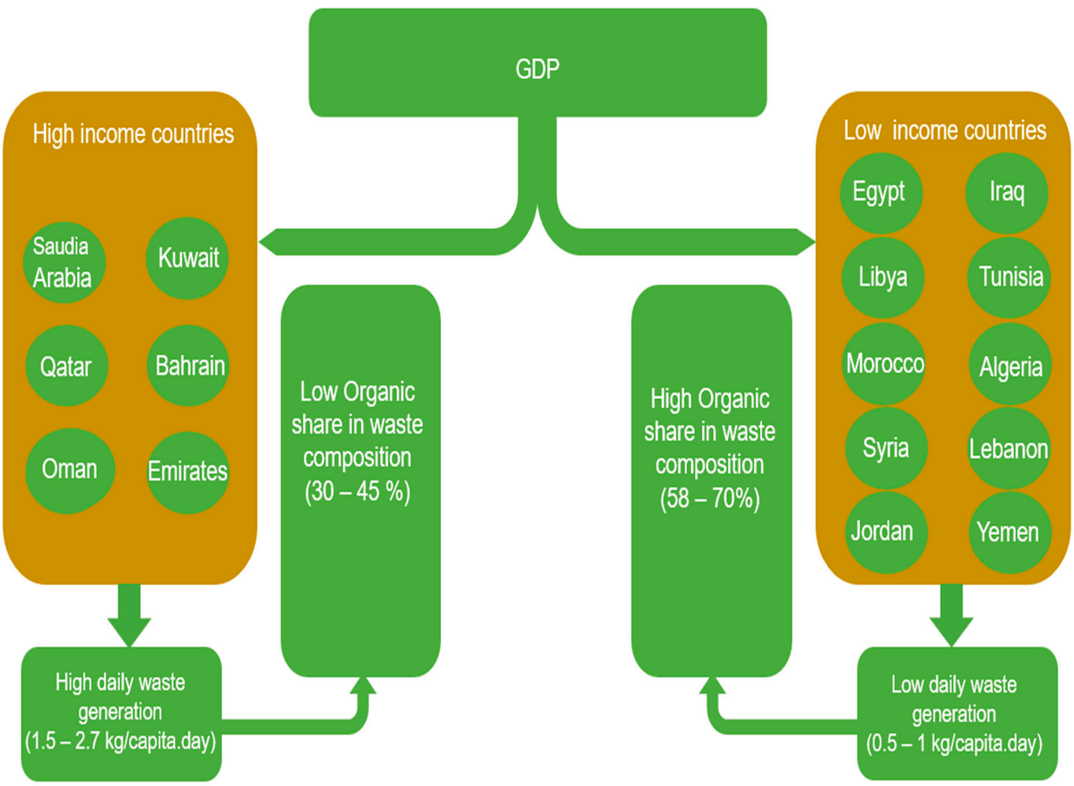

Figure 10. The effect of GDP as a key factor impacting the waste generation rate and waste composition.

In terms of energy consumption, low-income countries (oil importers) have the lowest rate of consumption, ranging from 220 kWh/capita in Yemen to 2200 kWh/capita in Jordan, while high-income countries (oil exporters) have a high rate of consumption, reaching 19,600 kWh/capita in Bahrain. This can be attributed to the low prices of the energy tariffs in such countries and the arid, harsh climate in summer.

13. Conclusions

The MENA region already faces a wide array of environmental stresses that include water scarcity, arable land depletion, air pollution, inadequate waste management, loss of biodiversity, declining marine resources, and the degradation of coastal ecosystems. Future development scenarios are expected to exacerbate these challenges, especially given that MENA is one of the regions that is most vulnerable to the impacts of climate change [86]. The GEO-6 report on West Asia reported that the waste crisis in the MENA region is a rising environmental concern, concluding that an approximate 3% median annual increase in municipal solid waste in the GCC and Mashriq countries will further disorder waste management systems [87]. Despite efforts from some Arab MENA countries (GCC members, Egypt, Jordan, and Tunisia) to develop legal frameworks and national strategies for integrative waste management, the lack of financial and technical resources to support the appropriate infrastructure, monitoring information, and designated entities hampers their implementation. Consequently, the waste process of collection–segregation–treatment–disposal is not functional and there is no significant waste-to-energy sector. A significant portion of solid waste is not collected daily (35% in Egypt, 26% in Syria, and 95% in rural Yemen) and segregating waste for reuse and recycling is mainly carried out by the informal sector [86]. Around 90% of the total solid waste in GCC and Mashreq countries is disposed of in dumpsites and unlined landfills, resulting in air, land, and groundwater pollution from hazardous chemicals, high GHG emissions (up to 12% of the national emissions, such as in Jordan [86]), and particulates produced from burning waste [7,12]. Moreover, the effect of the political conditions and conflicts in countries in the region, such as Syria, Libya, and Yemen, negatively impacts waste generation and changes the applicable strategies employed in the waste sector; for example, in the case of Lebanon, 15.7% of the country's total municipal solid waste generation occurs because they are hosting their neighbors (Syrian people) due to the war and conflict in that country [86]. In conclusion, the following points can be raised as gaps or offer a perspective on the waste management system in MENA region countries:

- Inadequate rules and regulations to stop the dumping of waste and decreasing the landfilling process gradually by increasing and supporting other streams of waste treatments.
- Lack of a reliable database and trusted tracing systems for waste collection and transportation. A solid background and periodically updated data, especially regarding the amount of waste generation and composition, are essential for developing an integrated waste management system.
- Lack of regional cooperation across all countries of the region and a failure to exchange data.
- Unclear tariff scheme for waste services introduced by the municipalities for the citizenship. In the best case, cost recovery through tax or included in power bills covers 30–40% of the expenses of the government.
- Infrastructure unprepared to enable certain types of development or additives in the waste sector, such as separation at the source, and poor strategic plans to encourage the private sector to invest in the waste system.
- Some countries in the region (Algeria and Tunisia) have very efficient regulations regarding the industrial sector and their responsibility toward waste generation, known as extended producer responsibility (EPR). However, this needs to be applicable in reality and further developed, which requires an updated database for the industrial sector and extended cooperation and coordination among the responsible institutions.

- At present, waste is considered garbage that needs to be disposed of. Awareness is low among society about the importance of the waste sector as a viable component of the circular economy and environmental protection. Recently, waste management has begun to be included as a comprehensive engineering program in universities. Awareness of this sector needs to be increased among the poor strata of society to ensure the integrated development of the entire sector.

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