energies

Review

Review of Bioenergy Potential from the Agriculture Sector in Iraq

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Abstract: Bioenergy is one of the most important renewable-energy sources worldwide, accounting for more than two-thirds of the renewable-energy mix. Biomass accounted for 13–14% of the primary energy consumption in 2018, and by 2050, it is expected to account for 50% of the global primary energy consumption. This article studies the biomass potential in Iraq. The potential of this country to be one of the leading producers of bioenergy is discussed, remarking on the importance of agricultural crop waste. Nowadays, Iraq generates a great quantity of biomass every year. Unfortunately, instead of contributing to the energy industry and economic progress, these wastes are burned directly, potentially causing a slew of environmental issues. Based on earlier studies, the theoretical energy potential of Iraq agricultural wastes is assessed. It is concluded that 10 million tons of dry agricultural leftovers can create 115 PJ of energy per year. According to the findings of this study, 10 million heads of cattle in Iraq could generate 72 million m^3 of biogas per day, with a total potential power of 946 TJ per year from animal wastes, mainly cattle dung. On the other hand, bioenergy potential is heavily reliant on the geographical distribution, availability, and accessibility of real waste. Wasit, Qadisiyah, and Mosul are the most feasible locations for this agricultural waste potential. This might lead to the development of a long-term economic plan for the successful and sustainable utilization of important accessible waste for bioenergy generation.

Keywords: biomass; renewable energy; gasifier; agriculture residues

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1. Introduction

Petroleum production is the main economic activity in Iraq nowadays. It drives economic trends and leads the overall exportations. Electricity generation in Iraq is a consequence of this economic profile, being highly dependent on fossil fuels. As a consequence of the strong dependency on conventional generation and the lack of alternative production units and a suited generation mix, the energy system in Iraq is considerably weak. One clear index of this issue is the increasing number of outage events registered throughout recent years, especially during summer, when high temperatures increase the necessity of cooling in dwellings and commercial buildings. This is due to the fact that demand and generation have not grown equitably. Actually, the gap between peak demand and maximum power supply has increased by a third. The abundant oil and gas reserves in Iraq enables its dependency on fossil fuels; however, Iraq also has high PV potential. Prospective studies have pointed out that PV generation may reach 5% of the overall generation capacity by 2030 [1–3].

As a result of globalization, population has increased worldwide and industrial development along with global energy consumption have risen substantially. The principal sources of energy are coal, oil, and natural gas, but they are finite and subject to depletion.

The COVID-19 crisis was a shock to the world energy system, but it regained ground in 2021, with a 4% rise bringing global energy consumption back to pre-pandemic levels [1]. The worldwide primary energy supply is made up of 81% crude oil, coal, and natural gas, including production, exports, imports, and bunkering. Renewable-energy consumption grew by 3% in 2020, while demand for all other fuels fell. Solar, wind, hydro, biomass, geothermal, and other technologies contributed two-thirds of the renewable-energy growth in 2021 [2]. The most important environmental issue nowadays is climate change. Biomass will play an important part in meeting human energy requirements among renewables, with the two primary choices being the replacement of fossil fuels with clean sources and the increase in energy efficiency. Biomass sources for fuel generation include plant and animal wastes. According to the International Energy Agency (IEA), the Iraqi energy industry is directly contributing to the environmental problem, with gas flaring alone releasing an estimated 30 million tons of carbon dioxide (CO_2) into the atmosphere [3].

Biomass production and the potential for renewable bioenergy generation vary per country, mainly depending on the location, resource availability, biodiversity, technology and economics. Biomass is predicted to provide 3000 TWh of electrical energy by 2050, thus reducing up to 1.3 billion tons of (CO_2) equivalent emissions per year, with each TWh creating 472.89 kg of (CO_2) [4]. Biomass is the most frequent source of fuel and bioenergy for heat power, electricity, and transportation in the European Union [5]. In 2018, solid biomass sources such as wood chips and pellets accounted for more than 65% of bio-power generation in Europe, with municipal trash accounting for roughly 20% and biogas accounting for 15%. Moreover, in the United States, power generated from biomass and garbage accounted for around 2% of the total electrical generation. Furthermore, rising nations such as India and Indonesia have followed a similar pattern. As the Indian government focuses on increasing power generation through renewable-energy sources, the power-generation capacity of biomass has risen dramatically in recent years. As the worldwide demand for renewable-energy sources grows, biomass-based power generation is predicted to rise at a high rate throughout the projection period [6].

To convert biomass into energy, various processes are required, which can be complex at times. Thermal and thermochemical transformation, biochemical transferring, and chemical conversion are four different types of processing technologies that are now available and might result in specific energy and renewable goods [7]. A variety of factors must be considered while selecting the correct technology, including technological robustness, environmental safety, and societal acceptability [8]. Modern bioenergy-conversion systems consider biomass gasification to be a suitable technology [9]. As a renewable fuel for creating several energy sources, biomass has many potentials. However, effective conversion processes must be applied in order to compete with fossil fuels [10]. In the United States, Germany, Spain, and Denmark, biomass cogeneration and combined heat-power (CHP) plants are widely deployed [11]. Bioenergy from biomass and biogenic waste accounted for 8.1% of the total primary energy consumption in Germany of 13,550 PJ in 2019, making it one of the most important countries that used energy in the production of electric energy at a rate of 22.7% in 2018, up from about 7% in 2013 [12,13].

Biomass fuels are often most effective and advantageous when utilized in biomass cogeneration systems to produce both heat and electricity (e.g., CHP). In traditional power-production systems, around 35% of the fuel energy potential is turned into electricity on average, while the remainder is released as waste heat. CHP systems combine the utilization of electricity and heat to attain a high efficiency of up to 90% [14]. The efficiency of a CHP system is determined by the technology employed and the system architecture. For example, the electrical output of phosphoric-acid fuel cells ranges from 37 to 42%, and may reach 85% when used in CHP systems. If the system takes advantage of the heat output, performance can increase up to 90% [15].

The thermal biomass sector in Spain continued to grow in 2019. It is estimated that more than 10.5 GW are currently installed, while heating systems account for 12% of all heating systems in the country, which includes single-family houses, apartment buildings and, increasingly, distributed heat networks. By the end of 2020, it is expected to be closer to 13 GW [16]. There have been many practical studies on using waste from the olive-oil business as a biomass source to generate thermal and electrical energy [17–19]. Numerous studies have also concentrated on wood biomass, which may be transformed into a variety of energy sources (heat, electricity, and biofuels), in most countries (e.g., see [20–22]). There are nine biomass power plants in operation worldwide. The most important are the Ironbridge power plant in the United Kingdom, with a 740 MW capacity, and a 205 MW plant located in Finland [23]. Biomass plants for gas-fired energy have a variety of advantages. Their operational efficiency is comparable to that of high-efficiency coal-fired power plants [24]. They greatly outperform commercially available direct-burning devices. They also reduce dependency on power while reducing CO_2 emissions, and provide an enticing option for the use of forestry and agricultural residues in order to regenerate rural economies [25,26].

Iraq is one of the countries with major undiscovered energy reserves. Available resources are restricted to the natural gas and oil that are used to fuel plants. Despite significant Iraqi biomass-energy resources, academics have paid little attention to biomass energy and its use in integrated heat and power facilities. The electrical shortage is one of the most difficult issues facing the Iraqi government, particularly given the increased demand during the summer, which is projected to be 30,000 MW. According to a statement from the Ministry of Electricity, the Iraqi power sector was able to achieve a production rate of 21,145 MW in 2021, which is the greatest rate ever achieved by the national electrical system [27]. According to broad measures to achieve economic and development returns, the plan involves moving forward with renewable-energy projects, electrical connections, and the adoption of the combined cycle for all power plants. Iraq generates massive volumes of solid trash each year. In 2020, around 12 million tons were generated only from municipal waste [28]. These wastes might be a treasure trove for governments if handled appropriately. Solid wastes can be repurposed and recycled as an energy source instead of being dumped in landfills or burnt [29]. Because there is a need for alternate energy sources, the transformation of these wastes into energy is the best option for both energy generation and waste disposal. Despite the availability of biomass-energy resources in Iraq, bioenergy and its usage in combined heat and power plants have received little attention.

In this context, the characterizations of five varieties of agricultural waste products from Iraq were investigated and evaluated for the possibility of use as fuel, either directly or indirectly, particularly for thermochemical processes such as gasification, combustion, and pyrolysis processes, according to [30]. Radiah et al. [31] aimed to discover the principles of microwave-assisted pyrolysis treatment for bio-waste as a sustainable raw-energy source, concentrating on the most desirable products of the microwave pyrolysis process, such as bio-oil, synthesis gas, and bio-char. Anssari et al. [32] investigated the economic feasibility of generating electricity from municipal garbage waste via the gasification method, and their findings show that the cost of the energy generated is lower than the average cost of the kWh generated using the conventional manner by the Iraqi Ministry of Electricity (42.5%). The effects of methanol and bioethanol in spark-ignition and compression engines have been explored by several researchers. Their experiments showed that adding methanol and ethanol to ordinary Iraqi gasoline and diesel is beneficial. The sulfur level in Iraqi diesel is significant (about 10,000 parts per million), whereas Iraqi gasoline has a low octane rating; bioethanol or methanol can be used to treat these two disorders [33,34].

This research examines the present condition of solid-waste-derived bioenergy, as well as its vital role in helping Iraq to improve its energy status towards a cleaner and more reliable paradigm. The primary goals of the research may be described as follows: (a) providing a look at the actual energy situation in Iraq, (b) examining the Iraqi electricity system, which is derived from a variety of renewable and non-renewable sources, (c) reviewing the existing Iraqi agricultural residue and municipal-waste potential to obtain a better knowledge of the existing situation and accessible resources, (d) calculating the energy potential of available residues, in addition to exploring the most essential conversion methods for turning biomass into various kinds of energy.

The remainder of the paper is laid out as follows: Section 2 discusses the most common conversion techniques for converting biomass into various types of energy. Sections 3 and 4 explain the basic state of electrical energy in Iraq, as well as its sources. Section 5 provides a summary of Iraqi biomass potential (solid waste, crop leftovers, and animal residue production). Lastly, Section 6 concludes the paper.

2. Energy Sector in Iraq: Current Status

In recent years, the capacity of generation of the Iraqi power sector has notably grown. Nevertheless, peak summer demand still frequently exceeds actual generation. Between 2008 and 2018, net power generation climbed by over 8% every year on average, reaching an estimated 78 billion kWh. According to the IEA, Iraq derives virtually all of its power (more than 97%) from oil and natural gas [35]. This section discusses the current state of electricity use and energy pricing in Iraq.

2.1. Electricity Generation

Iraq is the second-largest oil producer in the Organization of Petroleum Exporting Countries behind Saudi Arabia. However, Iraq is afflicted by a great power outage. The Iraqi electrical sector is facing several concurrent challenges. As a result of the disruption and destruction caused by the war, there has been at least one energy outage per year since 1991 [36]. Although the primary energy consumption has changed significantly in recent years, it has tended to rise between 2000 and 2019, peaking at 0.67 quadrillion Btu in 2019 [37]. Figure 1 depicts the evolution of Iraq energy output between 2013 and 2019. As seen, the total power output grew by around 58.5 GWh in 2013 to over 88 GWh in 2019. In this context, residential usage accounted for around 61% of the overall energy consumption in the same year as illustrated in Figure 2 [28].

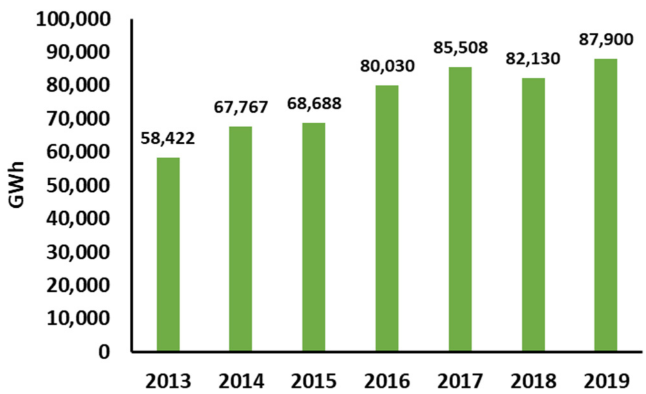

Figure 1. Cumulative annual values of electricity generated in Iraq in the period of 2013–2019 (data extracted from [28]).

2.2. Electricity Pricing in Iraq

Throughout 2021, electricity pricing was fixed at 0.024 $/kWh in Iraq for households, and 0.041 $/kWh for businesses, which encompasses all aspects of the electrical bill, such as power costs, taxes, and distribution. In contrast, the global average price of electricity for consumers during that period was 0.136 $/kWh and 0.124 $/kWh for companies [38]. Further subsidized tariffs were introduced in 2018, as shown in Table 1, and all residential customers, regardless of their total consumption, were subsidized at the same rate for the same level of consumption. Because of the price of energy-related items, the price of generating electricity using common fossil fuels such as gas and oil was the lowest [39].

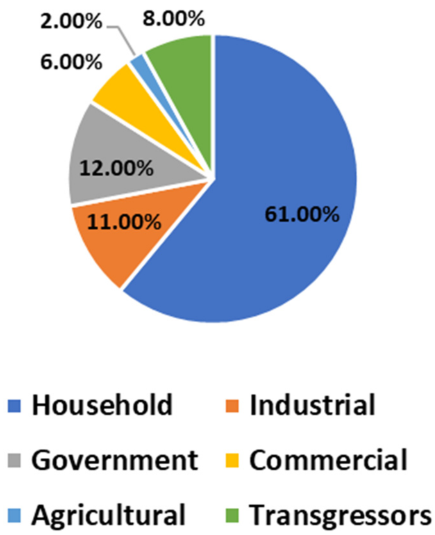

Figure 2. Consumption of electricity by sector in Iraq (data extracted from [28]).

Table 1. Summary of electricity tariffs in Iraq in 2018 [39].

Category	Monthly Consumption Range in Kilowatt-Hour (kWh)	Tariff In American Dollar ($ Per-kWh)
Residential	1–1500 1501–3000 3001–4000 4001+	0.0069 0.024 0.55 0.082
Commercial	1–1000 1001–2000 2001+	0.041 0.055 0.082
Industrial	All	0.041
Governmental	All	0.082

3. Resources of Electricity Generation in Iraq

In comparison to other sources of energy, the electrical energy generated by renewable energy in Iraq is inadequate. The major portion of electricity generation is attributed to thermal power plants (combined cycle, steam, and gas). Steam technologies such as gas and diesel stations are examples of fossil-fuel power stations. Figure 3 shows the number of operating stations and the percentage of their participation in the production of electricity in Iraq, where the production rates of gas, steam, diesel, and hydropower stations were 50 GWh, 26 GWh, 6.6 GWh, and 5 GWh in 2019, respectively [28]. Hydropower, which contributes 4% of the total renewable energy, is the only clean technology currently available in the country.

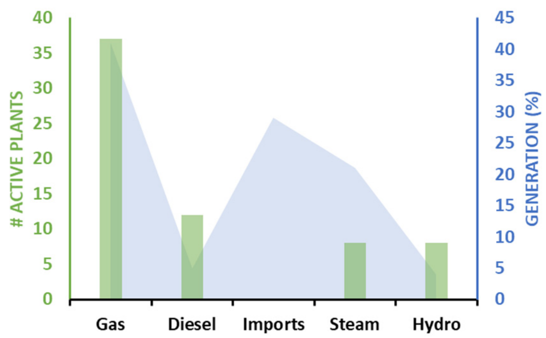

Figure 3. Number of energy stations and their generation rates in Iraq (data extracted from [28]).

3.1. Non-Renewable Sources

Iraq has 112 billion barrels of proven oil reserves, making it the second-largest oil producer behind Saudi Arabia. Electricity is mainly generated from crude oil, whereas oil and natural gas account for nearly all of the total electricity generation (more than 97%) [36]. Table 2 summarizes the current situation of fossil fuels and electricity generated in Iraq for the year 2019. Figure 4 shows the net generation of electricity, imports, and distribution losses in Iraq [35]. Oil and gas have been available across the country. The majority of Iraqi oil deposits are concentrated in the south, namely in the Basra, Maysan, and Dhi Qar governorates, but they are also available in the center and north of the country, as shown in Figure 5 [40].

Table 2. Iraq's energy profile from fossil fuels [41].

Type of Source	Annual Cumulative Values
Electricity installed capacity	123,205,304 MWh
Electricity production	87,899,993 MWh
Electricity consumption	42,086,620 MWh
Electricity exports	108,864,536 MWh
Electricity imports	35,305,311 MWh
Crude-oil production	4.61 m bbl./day
Crude-oil exports	3.09 m bbl.
Proven reserves of crude oil	148.80 billion bbl.
Natural-gas production	1.27 bn m^3
Natural-gas consumption	2.63 bn m^3
Natural-gas imports	1.36 bn m^3
The emissions of carbon dioxide from the energy consumption	188.14 m^3

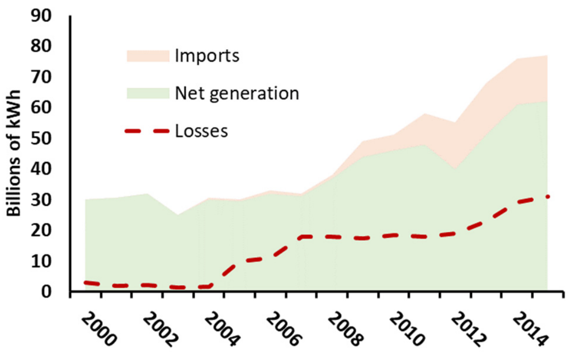

Figure 4. Net electricity generation, imports, and distribution losses in Iraq (data extracted from [35]).

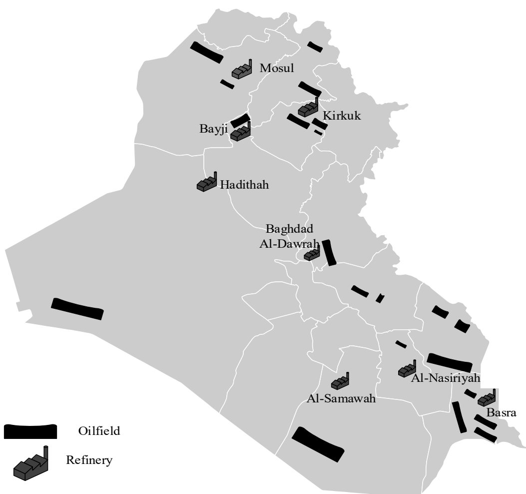

Figure 5. Iraqi oil concession zones.

Iraq depends on imports of some petrol products, mainly gasoline. The Iraqi electricity sector relies on Iran for much of its supply. In this regard, around 23% of electricity consumption was derived from Iranian natural gas, and Iraq purchased around 5% of its electricity from Iran in 2019 [35]. To avert a global energy crisis and environmental catastrophes, it is essential to consider alternative energy sources along with long-term plans to replace fossil fuels and raise the contribution of renewables to the major network sector.

3.2. Renewable Sources

Hydro, solar, wind, and biomass are the primary sources of renewable-energy generation in Iraq. However, they have not been profusely exploited, and there exists a high renewable potential in the country. Currently, Iraq is seeking to increase its use of renewable energy in order to decrease greenhouse-gas emissions. Renewable energy contributed to about 0.5% of the total actual consumption of primary energy in Iraq in 2018 [41]. In 2020, the eight hydroelectric stations participated in 4% of the electric power production in Iraq, thus contributing 5 GWh of energy [28]. The renewable-energy-capacity data in Table 3 indicate the highest net power capacity of Iraqi power stations and other facilities that use renewable-energy sources to generate electricity. The total capacity includes pumped storage, although the total generation does not. The capacity and generation data are reported in megawatts (MW) and gigawatt-hours, respectively (GWh) [42].

Table 3. Total renewable-energy production (PROD) and capacity (CAP) in Iraq.

Total Renewable-Energy Production in Iraq									
PROD (GWh)	2010	2011	2012	2013	2014	2015	2016	2017	2018
	4768	4142	4394	4805	2990	3334	4710	4640	2197
Total Renewable-Energy Capacity in Iraq									
CAP (MW)	2274	2274	1865	1895	1902	2311	2311	2311	2490

Iraq aspires to raise its renewable-energy-installation capacity. Indeed, under the Ministry of Electricity, the Iraqi Electricity Law No. 53 of 2017 relates to "encouraging and supporting the use of renewable energy, its nationalization, and operations". The Federal Government Program has set a goal of 1000 MWp of composite solar energy by the conclusion of the second year of the government's four-year term (2018–2022). The Ministry of Electricity has announced that their long-term goal is for wind, waste-to-energy, and geothermal technologies to account for 40% of the Iraqi electricity mix. To eliminate security risks, Iraq is also prepared to offer security (at no cost) to utility-scale power generators. The abundance of recently discovered natural gas and oil has reduced the need to investigate biomass as an energy option [43]. There are various benefits to generating energy from renewable sources, the most important is environmental protection and a shift away from reliance on natural gas and oil supplies. Moreover, this form of energy has an economic influence because it encourages investors to participate in initiatives that provide jobs and investment for young people.

4. Biomass Potential in Iraq

Iraq has a notable biomass-resource potential as a significant quantity of biomass is generated throughout the country [28]. In Iraq, the most important sources of biomass are municipal solid waste, agricultural waste (date palm, wheat straw, barley straw, rice straw, sorghum straw), and animal waste. The Central Statistical Organization of the Ministry of Planning announced that the contribution of the agricultural sector to the gross domestic product during the year 2020 reached 4.77%. Because of the scale of agricultural products, every year large amounts of waste are generated from this sector. Estimating the amount of possible agricultural leftovers, as well as their geographical distribution throughout Iraq is critical. In this sense, Figure 6 provides the geographical locations of cultivated areas in Iraq, of which Wasit, Qadisiyah, and Mosul are considered the most probable locations for these potentials [44].

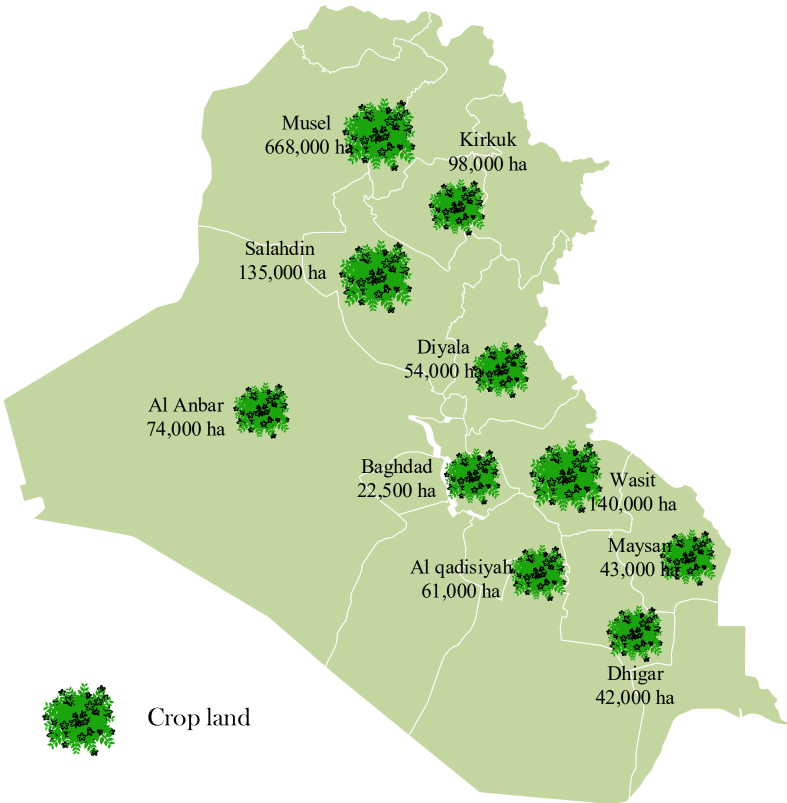

Figure 6. The geographical locations of the most important crops cultivated in Iraq.

Table 4 reports the values of seasonal-crop production according to the Iraqi Central Statistical organization for the year 2020. It also shows the approximate quantities of agricultural waste produced in tons per hectare according to the Food and Agriculture Organization (FAO) tool. The bioenergy and food security rapid appraisal of natural resources module was used to determine the availability of bioenergy feedstock from crop output, agricultural leftovers, and forestry. It calculates the amount of waste per hectare cultivated [45,46]. Wheat, barley, rice, and corn are the most important seasonal crops grown in Iraq that produce waste, but unfortunately, there are no statistics on this waste. Additionally, Table 5 shows the proximate and ultimate analysis of crop residue. All residue types and their sources are presented in Table 6 [47].

Table 4. Seasonal-crop production in Iraq.

	Barley Straw	Wheat Straw	Rice Straw	Sorghum Straw/Stalk
Residue yield (ton/hectare) [48]	1.94	3.16	5.79	4.10
Cultivated (Area in hectare) [28]	452,800	857,400	406,900	405,427
Production (ton) [28]	1,756,000	6,238,000	464,200	419,345
Residue quantities (ton) *	878,432	2,709,384	2,355,915	1,662,251

* Calculated according to the tool used by the Food and Agriculture Organization FAO [48].

It is essential to assess the possible quantity of agricultural leftovers and their geographic distribution in Iraq. Agricultural residues are divided into two categories: livestock leftovers and crop residues. Cereals such as wheat and barley are important agricultural goods. Dates, sheep and goat meat, chicken meat, and milk are also produced in Iraq. Shortly, the Iraqi national waste-management plan is projected to alleviate the solid-waste-management crisis. Given the temperature and availability of fertile land in Iraq, different energy crops such as sugarcane, sunflower, sorghum, and switchgrass have great potential for cultivation. Bioenergy is seen as a viable alternative to fossil fuels in the conversion process. Bioenergy has several advantages over other renewable-energy sources (wind, wave, solar, geothermal, etc.). Additionally, it is a low-carbon renewable-energy source; it has been shown that substituting bioenergy for fossil-fuel energy can result in significant reductions in greenhouse-gas emissions. Bioenergy, unlike other renewable-energy sources, is more adaptable, since it may be used to generate heat, power, and transportation fuels using a variety of technologies.

Table 5. Proximate and ultimate analysis of strategic seasonal-crop residues in Iraq [49].

Crops Residue	Heating Value		Proximate Analysis				Ultimate Analysis				
	LHV	HHV	Moisture Content	Ash Content	Volatile Matter	Fixed Carbon	Carbon	Hydrog	Oxygen	Nitrogen	Sulphur
Barley straw	15.14	16.53	11.53	5.20	67.33	15.94	40.87	5.04	36.75	0.53	0.07
Wheat straw	13.60	14.99	15.10	7.60	62.32	14.98	37.29	4.69	34.29	0.62	0.19
Rice straw	12.50	13.67	7.01	15.64	61.95	15.40	36.96	4.58	34.76	0.87	0.18
Sorghum stalks	15.47	16.80	5.97	6.47	69.11	18.45	43.32	5.42	38.20	0.37	0.25

LHV: lower heating value. HHV: higher heating value.

Table 6. Types of residues and their agriculture [47].

Type of Residue	Source
Straw	Barley, wheat, rice, broad bean, flax, sunflower, maize, cotton, sorghum, sesame, soybeans, sugar beet, peanuts
Bagasse	Sugar cane
Prunings	Citrus-orange, palm dates, grapes, olives
Manure	Chicken and cattle
Haulms	Soybeans, sugar beet, peanuts

Iraq is the sixth-largest oil producer worldwide, and petroleum and natural gas account for nearly all of the energy consumption in the country. Unfortunately, despite the availability of ideal circumstances for most types of renewable energy, successive administrations have failed to study the potential for renewable energy in Iraq due to the great accessibility of fossil energy [50].

Nowadays, governmental entities are becoming more concerned about the consequences of climate change and global warming. In response to this situation, developed countries have resorted to gradually moving away from fossil fuels and replacing them with biofuels from plant, municipal and animal waste. This represents an opportunity for some countries such as Iraq, which has a great biomass potential. In fact, Iraq accounts for many grain mills and date-processing plants. The wastes of these vital facilities can be properly utilized and converted into electrical energy or linked to the national grid. Thus, the Iraqi Ministry of Environment announced the beginning of international support for projects to improve the environment, and Iraq has practically begun to implement the concept of radical transformation to renewable energies, which is what the Iraqi government supports at the highest levels [51].

4.1. Crops Production

The Iraqi arable land makes up around one-eighth of the overall land area, while permanent pasture accounts for another tenth [52]. Iraq produces 0.4% of the world's wheat and is the 31st largest producer worldwide. In Iraq, the most important cereal is wheat, which is followed by barley, sunflower and sesame seeds, chickpea and dry broad bean in pulses, and sugar beet in industrial crops. Table 7 includes annual production quantities of wheat and barley in Iraq for the years 2014–2021 [28].

Table 7. Wheat and Barley production in Iraq [28].

	2014	2015	2016	2017	2018	2019	2020	2021
Wheat (1000 tons)	5055	2645	3053	2974	2178	4343	6238	4234
Barley (1000 tons)	1278	330	499	303	191	1518	1756	267

The palm is a strategic sector in the vast majority of countries, including Iraq, which has grown 629 distinct types of dates and generated three-quarters of the dates before the Gulf War. Due to a change in emphasis on the oil industry and decades of violence that damaged the farming system, the production of dates accounted for just 7.2% of the worldwide production by 2018 [53]. Agriculture crops produce a lot of waste, and these wastes consist of organic substances that result from the harvesting and processing of crops. As seen in Figure 7, crop waste is split into main and secondary residues.

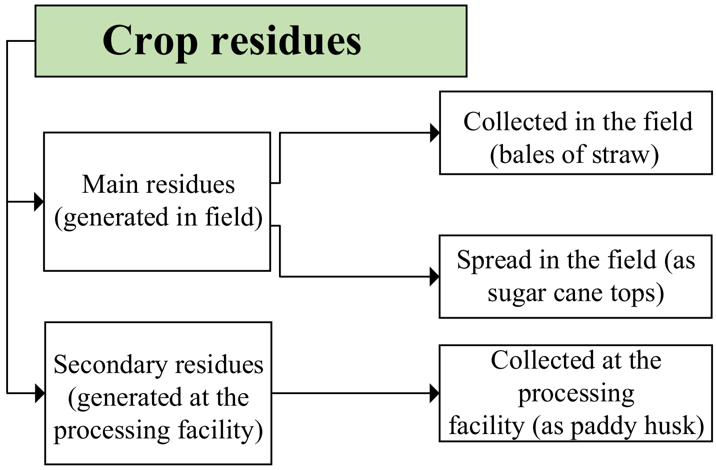

Figure 7. Crop-residue classification.

It was found that one palm tree generates an average of 40 kg of waste annually [54]. The number of date palms in Iraq is estimated at 17.3 million [28]. This results in 690 thousand tons of palm tree waste annually, which may be divided into two categories: main and secondary residues. Prunings of different kinds of fruit production are regarded as a viable feedstock for bioenergy generation, due to their physical features and high calorific values (HHV) [55].

The chemical composition of every agricultural product differs, and as a result, the potential energy of each specie differs. Many studies have been conducted to determine how to determine the potential energy of a crop [56–60]. These computations are based on a variety of factors, including annual agricultural residue production, a factor of availability, and a factor of dry weight [58]. Based on the approach described in [58], crop-residue energy potential was calculated. According to [61], the following equations for this strategy are explained:

The collectible dry biomass C_B is computed using the following Formula (1).

$$C_B = C_P \times R_F \times W_F \times A_F \tag{1}$$

where R_F is the residue factor, while C_P is the annual crop production, the dry-weight factor is W_F, and the availability factor is A_F [58,61].

The energy potential of crop residues, on the other hand, is calculated using the following Formula (2).

$$E_P = C_B \times O_C \times HHV \tag{2}$$

where O_C stands for organic content and HHV stands for the residue's higher heating value [58,61]. Table 8 reports the energy potential of various agricultural leftovers in 2020 based on crop production. The quantity of theoretical potential energy obtained from 10 million tons/year of dry biomass is 115 PJ/year, as shown in this table. Wheat and barley are the agricultural wastes that may yield the most energy.

Table 8. The energy potential of different crop residues available in Iraq for 2020.

Crops	C_P [28] 10^6 t/Year	R_F [58]	A_F [58]	W_F [58]	C_B 10^6 t/Year	O_C [58]	HHV [49,58]	E_P PJ/Year
Wheat	6.238	2.53	0.6	0.72	6.82	0.86	11.6	68.04
Barley	1.756	2.50	0.6	0.91	2.39	0.85	18.7	37.98
Sorghum	0.419	1.57	0.64	0.40	0.168	0.84	10.4	1.47
Rice	0.464	1.43	1	0.8	0.53	0.78	18.47	7.64
Total	-	-	-	-	10	-	-	115.13

4.2. Livestock Residues

Until 2019, Iraq had a cattle population of over 10 million. In addition, the total number of poultry projects was estimated at 4828 projects for the year 2020 [28,44]. Instead of burdening governments with the cost of disposing of these wastes without benefiting from them, a variety of animal wastes may be utilized to produce feed, fertilizers, and bioenergy. Manure from cattle and fowl is the most prevalent source of animal leftovers [62,63].

Another type of biomass utilized for energy production is animal wastes. Because of its chemical composition, livestock dung is regarded as a valuable source of biogas. Water makes up a large portion of livestock feces. Methane, the primary component of biogas, is produced during the anaerobic fermentation process. Biogas production is 0.3 m^3/day for every cubic meter of manure fermented [64]. The energy potential of animals can be calculated using the following Formulas (3) and (4) [65].

$$B_p = H_N \times C_S \times V_F \times X_F \times B_E \quad (3)$$

$$E_P = B_P \times M_F \quad (4)$$

where B_P stands for biogas potential (m^3 per day). The number of animal heads is denoted with H_N, V_F stands for daily volatile solids (kg/head/d), C_S stands for solid concentration, X_F stands for recovery factor (0.2), B_E stands for biogas yield per kg of volatile solid (0.22 m^3/kg) [56], E_P stands for energy potential, and M_F stands for methane-conversion factor (0.036 GJ/m^3). Applying the equations above to the particular case of Iraq resulted in a biogas potential (B_p) of around 72 million m^3/day from processing the manure of 10 million livestock, together with the total energy potential of 946 TJ per year. Table 9 shows a comparison of the theoretical results obtained in the current study that was conducted on agricultural residues and livestock manure. The real results are from Germany, where its biomass resources, which include secondary agricultural waste, forestry, municipal, industrial, and other waste are currently being exploited. Bioenergy produced in Germany accounts for about two-thirds of renewable energy [66].

4.3. Municipal Solid Wastes

Waste generated by municipal operations and services is referred to as municipal waste. Household garbage, building and demolition debris, sanitation residue, and rubbish from the streets make up municipal solid waste. The majority of this rubbish is created by residential and business complexes. The volume of municipal solid garbage has been quickly increasing and its composition altering as a result of expanding urbanization and changes in lifestyle and eating habits. In general, the more urbanized a region is, the more garbage that is generated per capita [67]. There is a link between higher welfare and the amount of municipal garbage [68]. In 2020, Iraq created an estimated 12 million tons of municipal solid garbage per year, according to the amount of per capita waste generated, which is 1.5 kg/day, according to Iraq's Central Statistical Organization [28].

The rise of the consumer world coincided with the end of the nineteenth century industrial revolution. In the currently polluted environment, understanding how to properly dispose of garbage has become critical. Local governments have used a variety of garbage disposal methods, including open dumps, landfills, sanitary landfills, and incineration facilities. Composting is one of the most essential waste-treatment processes, and segregation is an integral part of the municipal-solid-waste-management process [69].

Table 9. Calculations of energy production from potential wastes studied in Iraq.

	Agricultural by-Products [Million t]	Municipal Waste [Million t]	Total Residues in Germany Included Forestry, Industry, and Other Areas [Million t]	Total Energy Potential [PJ [66]	Comments
Theoretical biomass potentialIn Germany	44.6	18.5–18.8	151.0–152.7	1500–2600	Actually value the total energy potential from biomass
Theoretical biomass potentialIn Iraq	10	12	-	115	A theoretical value of the energy from the wastes of agriculture and cattle. PJ/year
-	Number of livestock [million]	Biogas Production [million m^3/day]	-	Total TJ/year	-
Theoretical energy from Cattle wastes	10	72	-	946	Energy from processing the manure of livestock

5. Bioenergy Technologies

Different techniques can be used to transform biomass into various forms of energy. The optimal selection might be influenced by a variety of circumstances, including the amount of biomass feedstock, the required energy form, environmental requirements, project-specific factors, and economic conditions [70].

The anaerobic digestion process uses wet raw materials, such as slurry, whereas the other methods use dry feedstock [71,72]. Pyrolysis is a chemical reaction that transforms biomass into tar, char, and low-weight gases [73,74]. The pyrolysis of biomass is widely utilized to produce chemical compounds such as fuel (bio-oil) and charcoal (into bio-char) [75]. In practice, biomass combustion is used for both heat (home boilers) and medium-large-scale power production (direct combustion and/or co-combustion with coal) [76].

Nowadays, the most important biomass-to-power conversion technologies are gasification, pyrolysis, combustion, and digestion as illustrated in Figure 8. Moreover, Figure 9 schematizes the existing technologies for converting biomass to energy, which could be used in a wide range of industries and operations [77,78].

Biomass gasification is considered a promising biomass-to-electricity technology that can be used not only in small-scale CHP systems but also in large plants, such as those using lignite, which does not ignite in combustion boilers. In terms of economies of scale, it appears that investing in larger factories is more lucrative and generates greater economic advantages [79,80].

Small-scale gasification plants achieve relatively high power-to-heat ratios for bioenergy systems with limited capacity, making them an appealing solution for decentralized applications. Electricity and heat production, chemical feedstock, and transportation fuels are all products of biomass-conversion systems [81]. Cogeneration systems are regarded as one of the most effective technologies available. This system may provide both heat and electricity. Electricity surpluses can be sold to the public power grid. When compared to systems that generate heat and electricity independently, combining thermal and mechanical energy from basic sources of energy such as coal, natural gas, oil, or biomass enables considerable savings in terms of money and energy, as well as increased operational efficiency [82].

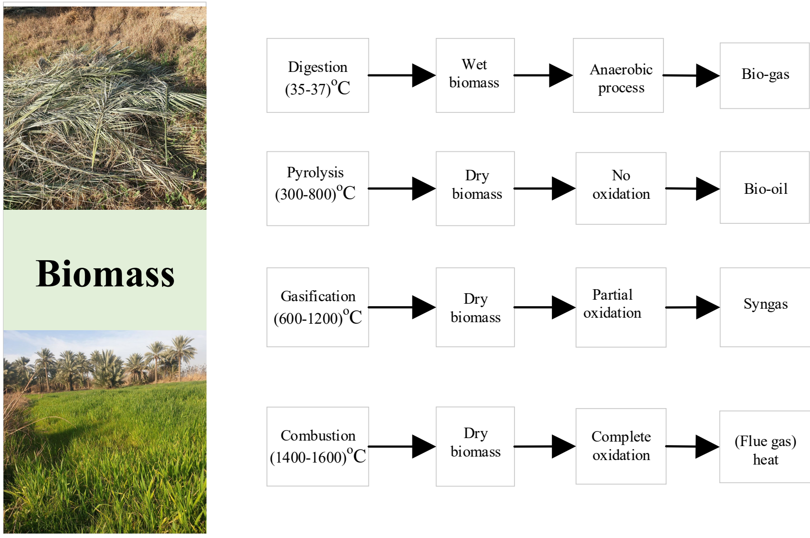

Figure 8. Technologies for biomass conversion.

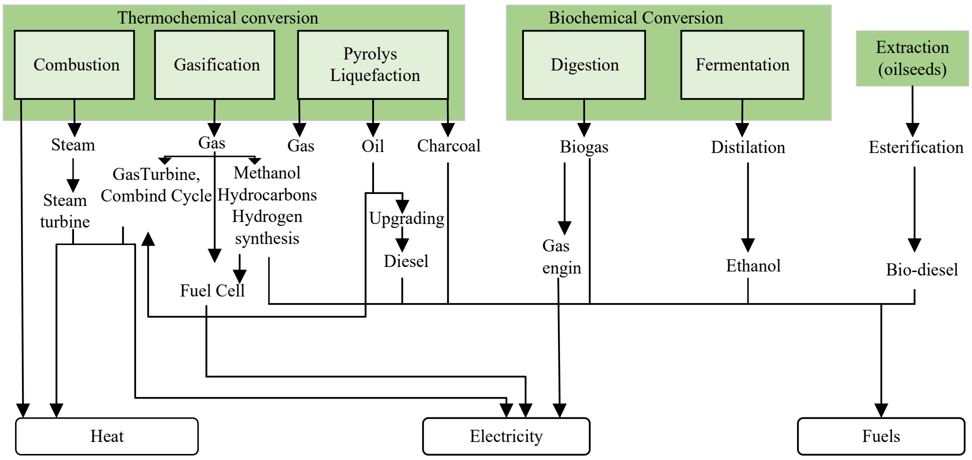

Figure 9. Scheme of technologies for converting biomass to energy.

The fundamental feature is the capability of generating both power and usable heat through a single basic energy-consumption process. This combined generation increases the efficiency of the process by 30% on average compared to traditional generation technologies. The amount of fuel used for energy is cut in half with this technique [83]. Many countries use gasification technology to convert biomass to energy, and gasification has been increasingly important in Germany's growth of renewable-energy generation, with the number of erected thermo-chemical gasification facilities quickly increasing in recent years. The fundamental benefit of biomass gasification is its high power-to-heat ratio, which significantly reduces pollutant emissions due to power generation. This is because of the increased electrical efficiency of gasification plants, which results in higher power-generating revenues [84].

Iraq possesses considerable biomass resources, but the abundance of newly discovered oil and natural gas has reduced the need to investigate biomass as an alternative energy source. A study undertaken by a group of Iraqi academics studied the possibilities of employing diverse types of waste in the production of methane gas without relying on a single type. When compared to other types of power plants, the production costs are minimal, which was proved in their investigation by yielding electrical energy at a rate of (38.5 MW/h) [85].

6. Conclusions

Fossil fuels were and still are the main source of energy production in Iraq. Iraq has electricity power shortages, and several obstacles must be overcome in order to satisfy the projected rises in electrical demand. This analysis discovered that wind, solar, and biomass energy are currently underutilized, but that they might play a key part in a sustainable-energy future for the country.

Biomass has emerged as one of the most essential energy sources for the majority of the globe. Despite the availability of many biomass sources in Iraq, they have not been utilized to help improve energy-sector production. Iraqi farmers use animal fertilizer, agricultural residues and bioenergy as a cost-effective and ecologically friendly approach to fertilize their crops and provide cooking gas for their houses. With the advancement of conversion technology, it may be utilized to generate electric power on a greater scale, as is the case in many nations.

Crop leftovers are accessible in quantities of roughly 10 million tons per year. Wheat straw, barley straw, rice straw, and prunings provide the majority of these leftovers. This amount of agricultural residue has the capacity to produce 115.13 PJ of potential energy every year. There are also roughly 0.5 million tons of palm-tree trash and agriculture leftovers accessible each year. In addition, the research estimates that 10 million cattle in Iraq could produce 72 million cubic meters per day of biogas, with a total annual energy potential of 946 TJ.

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