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DETERMINING AND MAPPING BIOMASS ENERGY POTENTIAL FROM AGRICULTURAL RESIDUES IN SYRIA

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Abstract: Syria faces a problem of restricted access to fossil fuels due to limited resources. In this paper, the potential of biomass and the energy value produced from agricultural residues for 32 agricultural crops has been studied. Data from the Syrian Ministry of Agriculture for the year 2016 were utilized to determine the total annual potential of field and orchard agricultural residues using the residue-to-product ratio. The study also examined the distribution of regions with the highest production of agricultural waste in the country. The research found that approximately 1.93 million tons of agricultural residues were produced, with 0.698 and 1.213 million tons for field and orchard crops, respectively. The most significant agricultural residues came from olive trees, wheat plants, and orange trees, accounting for 35%, 11%, and 10%, respectively. The possible heat value from field and orchard crops was 23972 and 44932 Btu, respectively. This quantity provides 17.6% of Syria's energy consumption. The provinces with the highest production of agricultural residues were Aleppo, Lattakia, and Tartus, with values of 12.35, 11.8, and 8.04 PJ, respectively. According to the study, agricultural residues in Syria have the potential to be a sustainable source for biomass.

Keywords: Biomass, Syria, Green energy

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1. Introduction

Syria is a country with a rich agricultural history. Historically, agriculture has been a cornerstone of the Syrian economy, providing livelihoods for a significant portion of the population. However, due to the war, oil wells ceased operations, and traditional agricultural practices were disrupted, leading to a decline in agricultural productivity. With the depletion of fossil fuel resources in Syria, according to 2017 statistics the country's production dropped to only 47.8% of its energy needs (WHO, 2022). Globally and particularly in Syria, the use of biomass from agricultural residues is considered essential to meet energy needs (Hamza, 2007). The biomass residues referred to here are the leftovers after harvesting the main crop in agriculture, including stem cutting, trimming, straw, stalks, leaves, and branches (Karaca, 2023), which are valuable energy resources. Biomass can be converted into energy production, which can be used for electricity generation and heating, serving as an alternative to traditional cooking fuels, especially in rural areas with limited access to conventional energy sources (Tun et al., 2019). By utilizing biomass energy, economic development and increased investment can be achieved. Encouraging rural communities to engage in the collection and processing of biomass residues creates investment opportunities. Project owners can establish small facilities for biomass processing, providing employment opportunities and stimulating economic growth. This, in turn, reduces reliance on central energy networks and improves living conditions (Ginni et al., 2021). Additionally, biomass residues are directly linked to crop production during agricultural activities. The more crops produced, the more crop residues generated, as residues constitute a certain percentage of the total crop (Karaca, 2022). The energy potential of biomass can be calculated if these parameters are known. Crop production and biomass residues, along with their agricultural development, depend on environmental factors such as climate and soil (Avcıoğlu et al., 2019).

Several studies have been conducted on the potential of biomass resources worldwide. These studies have been published to assess agricultural biomass residues and their potentials. (Shahbeik et al., 2024) it was found that converting agricultural residues into biofuel using the Hydrothermal Liquefaction (HTL) method holds promise in alleviating financial burdens associated with fossil fuel use, (Wang and Wu, 2023) found that biomass has proven itself as a primary fuel, contributing to reducing carbon emissions in the electricity grids of the United Kingdom. Therefore, it is regarded as highly important for mitigating greenhouse gas emissions.

(Naeimi et al., 2023) studied the possible heat value of agricultural residues available for 10 agricultural products in Azerbaijan, and the value was found to be 19.61 T.J. The most contributing crops were thin maize and tobacco. (Askarova et al., 2022) studied the potential of renewable energy in Kazakhstan and found that the country could annually produce 37.26 million tons of biomass resulting from waste, with the potential to generate 466.47 P.J of energy. This accounts for 61% of the country's total energy production. The study also highlighted that dry agricultural residues could be burned with coal in power plants. (Avcıoğlu et al., 2019) identified the agricultural biomass energy potential in Türkiye. The study utilized characteristics of agricultural residues, moisture levels, and low heat values for dry matter. A mathematical model was developed to calculate the energy potential of agricultural biomass residues. The theoretical biomass quantity and energy potential were determined for field crops and orchard crops in Türkiye, amounting to 59.43 kilotons and 15.882 kilotons, respectively. The total available energy from biomass residues was estimated at 298.955 T. joules for field crops and 65.491 T.J for orchard crops.

Demirel et al. (2019) utilized the waste-to-product ratio to study the energy potentials of crop residues in Sudan. The thermal energy was approximately 154 gigajoules for the 2015 crop, with thin maize being the largest contributor. Karaca (2019) determined the biomass potentials and the possible energy production values for agricultural residues in the Hatay province. The total thermal value of agricultural residues was found to be 13.36 gigajoules. The aim of this study is to identify the biomass potentials and energy produced from agricultural residues in Syria to reduce dependence on imported fuels and maintain energy security.

Tun and Juchelková (2019) studied the importance of using biomass energy in the agricultural and livestock sectors to mitigate the consumption of fossil fuels in the energy sector. They found that biomass energy could cover 50% of the total energy consumption in the country. The energy generated from residues was 15.9 million tons of oil equivalent (Mtone). Karaca et al. (2017) studied the potential of agricultural biomass residues in the Samsun province of Türkiye. The total heating value (THV) was found to be 6.46 GJ, with hazelnuts being the major contributor.

In the first part of the study, agricultural biomass residues in Syria were examined. The structural and physical characteristics of different crop types were determined to obtain the energy potential of biomass residues. These characteristics included the residue-to-product ratio, residue moisture, and residue energy value. Based on these values, it was possible to identify agricultural crops containing biomass residues with higher energy potentials. In the second part of the study, theoretically, the potential energy values available for Syria were calculated using computed values such as residue moisture and residue product ratio. The study explored crops that produce larger biomass and, consequently, higher energy potentials. It is important to know the regions where crops are intensively cultivated, the types of residues they produce, and the characteristics of these residues, as well as their energy capacities. This information is crucial for making informed decisions about the installation of renewable biomass energy stations and sustaining energy supplies based on biomass residue potentials.

2. Materials and Methods

The study was conducted in the Syrian Arab Republic, situated between latitude 32 - 37.5 degrees north and longitude 35.5 - 42 degrees east of Greenwich. Syria is considered part of the Asian continent, covering an area of 185,180 square kilometers, divided into 14 provinces: Damascus, Rural Damascus, Homs, Hama, Aleppo, Lattakia , Tartus, Sweida, Daraa, Quneitra, Idleb, Al-Raqqa, Dair-Ezzor, and Hassakeh. It should be noted that Damascus is solely a residential area and does not contain agricultural lands. The Mediterranean climate predominates in the coastal region, while the climate varies based on geographical location and topography. The coastal areas experience a more moderate climate, with hot and dry summers and mild, rainy winters. The vegetation consists mainly of shrubs influenced by the Mediterranean climate. The central and eastern regions of Syria, on the other hand, have a desert climate.

According to data from the Syrian Ministry of Agriculture, the arable land in Syria amounts to 6.082 million hectares, of which 5.77 million hectares are utilized. Agricultural production for the studied field crops in this research reached 4.215 million tons, and 2.966 million tons for orchard crops. The studied area for field crops encompasses 2.711 million hectares, while orchard agricultural land covers 1.042 million hectares. In total, the areas studied in the research constitute approximately 3.75 million hectares, representing 65% of the total cultivated agricultural land in Syria.

2.1. Selection of Agricultural Crops for Biomass Residue

An annual production energy of 4.2 million tons of field crops suitable for agriculture and over 2.865 million tons of orchard crops was chosen for evaluation of the biomass potential in Syria. A total of 32 different crops were considered in two categories. These are listed below:

- Field Crops Studied: Wheat, barley, potatoes, corn, cotton, sunflowers, beans, lentils, tomatoes, red watermelon, onions, chickpeas, sugar beets, peanuts, sesame, and tobacco.

- Orchard Crops: Olives, grapes, apples, oranges, mandarins, lemons, apricots, plums, peaches, pomegranates, cherries, pears, figs, pistachios, walnuts, and almonds.

Based on the 2016 statistics from the Ministry of Agriculture and Agrarian Reform, the annual production quantities for the 32 crops in the country were collected. Residue types from crops (straw, stalks, peels, stem leaves, pruning, etc.) were selected, and the amount of waste production, its percentage, and its lower heating value (LHV) were obtained. Data analysis was performed based on the physical characteristics of agricultural and orchard crop residues presented in Table (1). The crop product quantity (AAP), residue product ratio (RPR), lower heating value (LHV), and availability ratios (A) were used in the mathematical model that was introduced. The total heat value from agricultural production were calculated, as shown in the flowchart in Figure (1).

2.2. Calculation of Available Agricultural Residues (AAR):

The value of ARR (Available Agricultural Residues) represents the total annual production of biomass obtained from agricultural residues. The ARR value varies depending on the quantities of agricultural production in tons (AAP), the percentage of residue product ratio (RPR), and the percentage availability of residues (A). ARR is calculated according to the equation 1 (Karaca, 2015)

$$ARR=AAP*RPR*A \quad (1)$$

Residue product ratio (RPR) vary from one region to another depending on agricultural practices and alternative uses of residues. For example, when rice is cut about 5 cm above the ground, the RPR value is 1.75; if it is cut more than 5 cm during harvesting, the RPR will decrease by up to 0.452 (Avcıoğlu et al., 2019).

2.3. Calculating the Potential Available Energy

Equation 2 below was utilized to compute the potential energy available for dry biomass: (Jorjani et al., 2021).

$$THV=AAR*LHV \quad (2)$$

where THV is the total heat value of agricultural residues in GJ, and LHV is the lower heat value of dry crop residues in MJ.kg^{-1}. Values for PRP, A, and THV were obtained from previous research, as presented in Table 1.

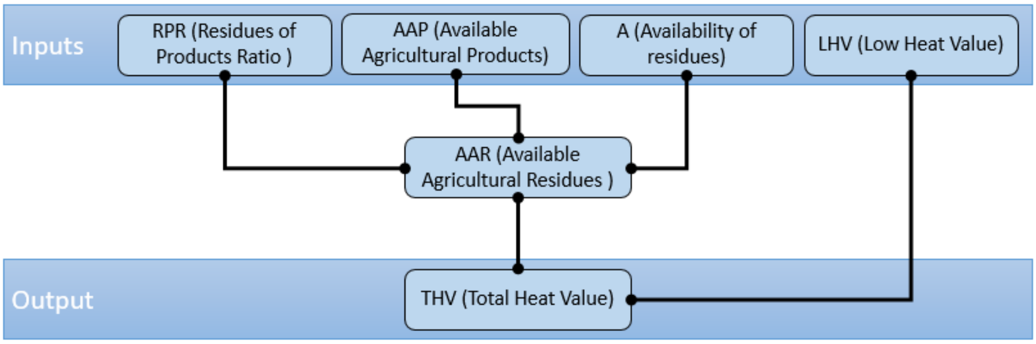

Figure 1. is a flowchart for calculating the total heat value.

Table 1. Residue of products ratio, availability, and THV for residues of major agricultural crops in Syria

Crops	(AAP) 1000 Ton	Area 1000 Ha	Residues	RPR	A%	LHV Mj	Reference
Wheat	1726	1179	Straw	0.8	15	17.9	(Karaca et al., 2017)
Barley	954	1244	Straw	0.9	15	17.5	(Karaca et al., 2017)
Potato	507	22	Vines	0.1	50	15.34	(Soucek and Jasinskas, 2020)
Tomato	415	9	Stalks	0.3	60	13.7	(Akinbomi et al., 2014)
Watermelon	213	7	Stalks	0.15	50	20.5	(Ronzon and Piotrowski, 2017)
Lentils	113	123	Stalks	1.74	20	14.7	(Unal and Alibas, 2007)
Maize	79	18	Stalks	1	60	18.5	(Karaca et al., 2017)
	79	18	cob	0.64	60	18.4	(Karaca et al., 2017)
Dry Onion	79	5	Husk	0.1	100	16.51	(Malaťák and Dlabaja, 2016)
Cotton	41	17	Stalks	2.3	60	18.2	(Karaca, 2019)
Chickpeas	31	56	Stalks	1.3	60	18.5	(Karaca, 2019)
Sugar beet	11	12	Roots	1	40	17.21	(Brachi et al., 2017)
Tobacco	8	0.3	Roots	2.27	60	16.1	(Turker et al., 2022)
Peanut	7	7	Stalks	1.5	60	18	(Gao et al., 2016)
	7	7	Hull	0.28	60	18	(Gao et al., 2016)

Table 1. Residue of products ratio, availability, and THV for residues of major agricultural crops in Syria (continue)

Crops	(AAP)	Area	Residues	RPR	A%	LHV	Reference
	1000 Ton	1000 Ha				Mj	
Beans	26	7	Root-Leaf	1.45	15	14.7	(Turker et al., 2022)
Sunflower	3	3	Stalks	2.5	60	14.2	(Karaca, 2019)
Sesame	2	2	Stalks	0.5	56	12.4	(Demirel et al., 2019)
Total	4215	2711.3					
Fruits Crops							
Orange	725	26	Pruning	0.35	80	18.1	(Turker et al., 2022)
Olives	668	692	Pomace	0.4	90	19.7	(Karaca, 2019)
	668	692	Pruning	1.2	50	18.5	(Turker et al., 2022)
Apples	452	52	Pruning	0.19	80	17.8	(Turker et al., 2022)
Mandarin	260	11	Pruning	0.28	80	17.6	(Turker et al., 2022)
Grapes	213	47	Pruning	0.42	80	18.0	(Turker et al., 2022)
Lemon	188	7	Pruning	0.3	80	17.6	(Turker et al., 2022)
Cherries	76	29	Pruning	0.19	80	21.7	(Turker et al., 2022)
Pomegranate	3149** 69.9	5	Pruning	9	80	17	(Karaca, 2019)
Almond	55	72	Pruning	0.6	80	18.2	(Turker et al., 2022)
Peach	52	7	Pruning	0.4	80	18.2	(Turker et al., 2022)
Apricot	50	14	Pruning	0.19	80	20	(Turker et al., 2022)
Pistachio	50	60	Pruning	0.44	80	18.5	(Turker et al., 2022)
Fig	39	9	Pruning	0.21	80	18.2	(Turker et al., 2022)
Plum	1450** 31.1	4	Pruning	7	80	17.3	(Karaca, 2019)
Pear	26	4	Pruning	0.22	80	18.2	(Turker et al., 2022)
Walnuts	11	3	Pruning	0.66	50	19	(Gürdil et al., 2021)
Total	2966	1042					
Total Summation	7181	3753.3					

**1000 trees.

3. Results and Discussion

Agricultural residues in the studied crops amounted to 0.698 and 1.213 million tons for field and orchard crops, respectively. The potential heat value from field and orchard crops was 23.972 and 44.932 million gigajoules. For field crops, Table (2) indicates that the per-hectare production of agricultural residues is 14.64 tons. This value reflects a high productivity level for agricultural residues. The per-hectare production in Syria for tomatoes is good, reaching 8.3 tons, while corn and cotton yield 4.318 and 3.328 tons of agricultural residues per hectare, respectively. In orchard crops, the per-hectare productivity of orange agricultural residues is 7.8 tons compared to olives, which amount to 0.92 tons per hectare. The per-hectare productivity of mandarins and lemons is high, reaching 5.294 and 6.445 tons, respectively. On the other hand, barley and wheat have low per-hectare productivity, amounting to 0.103 and 0.175 tons, respectively.

Based on the agricultural land area for each crop and the per-hectare productivity of agricultural residues, Figure (2) illustrates the percentage of agricultural residues for each crop. In Syria, olives constitute 35% of the total weight of agricultural residues, primarily due to the extensive cultivation areas and the utilization of olive pomace as agricultural residue. Oranges constitute 10% of agricultural residues despite being cultivated on only 26 thousand hectares. The high per-hectare productivity of agricultural residues contributes significantly to this percentage. Apples represent 6% of agricultural residues and are cultivated on 52 thousand hectares. Corn accounts for 4% of the weight percentage of agricultural residues and is grown on an area of 18 thousand hectares. Both cotton, tomatoes, and mandarins each contribute 3% to the total weight of agricultural residues. However, it's worth noting the high per-hectare productivity of tomato residues, cultivated on only 9 thousand hectares but with a yield of 74.7 thousand tons. In contrast, cotton is grown on 17 thousand hectares with a yield of 56.58 thousand tons.

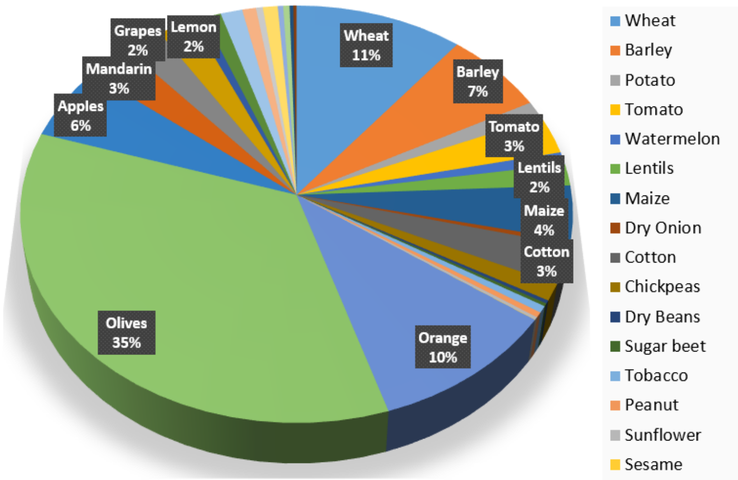

Figure 2. AAR of major crops in Syria (%).

Table 2. Values of AAR and THV variables and hectare productivity

Crops	Area (1000 Ha)	AAR (Ton)	THV (GJ)	AAR/ha
Wheat	1179	207120	7414896	0.175
Barley	1244	128790	4507650	0.103
Potato	22	25350	777738	1.152
Tomato	9	74700	2046780	8.3
Watermelon	7	15975	654975	2.282
Lentils	123	39324	1156125.6	0.319
Maize	18	77736	2870165	4.318
Dry Onion	5	7900	260858	1.58
Cotton	17	56580	2059512	3.328
Chickpeas	56	24180	894660	0.431
Dry Beans	12	10400	357968	0.86
Sugar Beet	0.3	4400	482420.4	14.64
Tobacco	7	7200	259200	1.02
Peanut	7	2698.5	87097.5	0.38
Sunflower	2	4500	127800	2.25
Sesame	3	560	13888	0.186
Total	2711.3	697995.5	23971733.5	
Fruits				
Orange	26	203000	7348600	7.80
Olives	692	641280	24304512	0.92
Apples	52	68704	2445862.4	1.321
Mandarin	11	58240	2050048	5.294
Grapes	47	71568	2576448	1.52
Lemon	7	45120	1588224	6.445
Cherries	29	11552	501356.8	0.398
Pomegranate	5	22672.8	770875.2	4.53
Almond	72	26400	960960	0.366
Peach	7	16640	605696	2.37
Apricot	14	7600	304000	0.542
Pistachio	60	17600	651200	0.293
Fig	9	6552	238492.8	0.728
Plum	4	8120	280952	2.03
Pear	4	4576	166566.4	1.14
Walnuts	3	3630	137940	1.21
Total	1042	1213254.8	44931733.6	
Total summation	3753.3	1911250.3	68903467.1	

Table 3. Distribution of agricultural residues and the amount of the annual total calorific value in the Syrian governorates and their percentages

Governorate	Residues-AAR (Ton)	Share in Total Residues (%)	Total Heating Value – THV. (GJ)	Share in Total Heating (%)
Aleppo	345078	18.09	12569097	18.28
Lattakia	330558	17.32	11992486	17.43
Tartous	218946	11.47	8072696	11.74
Al-Hassake	206344	10.82	7198417	10.47
Al-Raqqa	159741	8.37	5808792	8.44
Hama	160847	8.43	5771469	8.39
Homs	134816	7.06	4948290	7.19
Idleb	101155	5.3	3670342	5.33
Damascus Countryside	81495	4.27	3015555	4.38
Dar'a	81022	4.24	2622933	3.81
Sweida	58014	3.04	2047163	2.98
Dair-Ezzor	24137	1.26	860117	1.25
Quneitra	5299	0.27	188403	0.27
Total	1907458	100	68765766	100

Table (3) shows the distribution of agricultural waste in each governorate and the percentage of agricultural waste in each governorate. It can be noted that the city of Aleppo is more productive of agricultural waste, as it produces 345.07 kilotons of agricultural waste, or about 18.09% of the total weight value of agricultural waste, as it accounts for 40.6%. Of potato production, 32.5% of chickpea production, 29.5% of sesame production, and 29.9% of pistachio production, Figure (3), and the resulting agricultural waste can generate thermal energy amounting to 12.57 PJ, Table (3).

According to the table, Lattakia province produces 330.5 kilotons of agricultural residues, approximately 17.32% of the total quantity. Despite its smaller area compared to eastern cities such as Al-Hassakeh and Deir Ezzor, Lattakia plays a significant role due to cultivating 87.5% of oranges and 78.8% of mandarins, resulting in higher agricultural residue production. The estimated annual thermal energy value obtainable from Lattakia is 11.99 GJ. Tartus province produces 218,946 kilotons of agricultural residues, accounting for 11.47% of the total quantity. Tartus province contributes significantly to the production of 58.2% of lemons, 33.9% of dry beans, 20% of olives, and mandarins.

The city with the least production of agricultural residues is Quneitra due to its small area of 180 square kilometers. As for Dair-Ezzor province, the limited agricultural residue production can be explained by the ongoing war. In 2011, it produced 47,159 tons of corn, 105,029 tons of cotton, 185,258 tons of sugar beets, and 2,119 tons of sesame) (Syrian Ministry of Agriculture, 2011). However, there are no available data for these crops in 2016. Al-Raqqa and Al-Hassakeh, despite dominating wheat and barley production, contribute 10.47% and 8.44% of agricultural residues, respectively, due to the diversity of crops cultivated in Al-Hassakeh, as shown in Table (3).

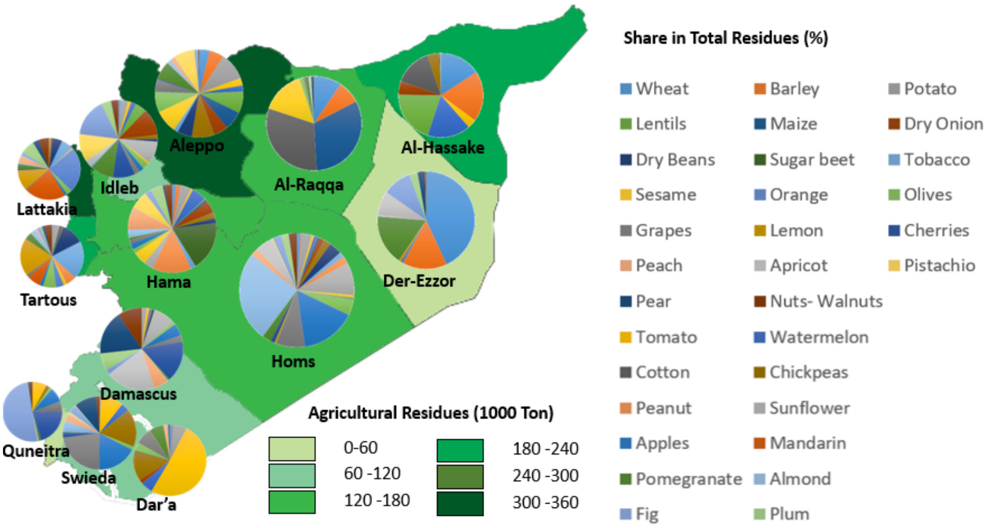

Figure 3. Map of agricultural residues distribution in Syria.

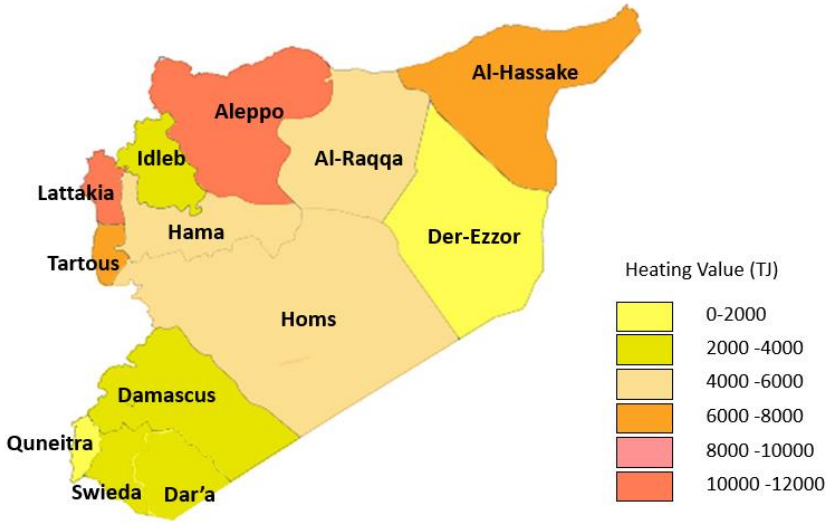

Figure 4. The distribution map of heating value based on agricultural residues in Syria.

Table 4. The production per hectare from agricultural residues in several countries compared to Syria

Country	Arable land 10^6 Ha	AAR 10^6 Ton	Productivity (Ton/Ha)	References
Türkiye	23.95	75.084	3.13	(Avcıoğlu et al., 2019)
Sudan	19.82	11.2	0.56	(Demirel et al., 2019)
Azerbaijan	2.09	1.09	0.52	(Naeimi et al., 2023)
Syria	3.75	1.91	0.51	

From Table (3), we observe that the production per hectare from agricultural residues is acceptable compared to Sudan and Azerbaijan but is low compared to Türkiye. The results can be explained by the soil fertility, crop diversity, and the utilization of modern technology in agriculture (Akkoyunlu, 2013). Additionally, the war in Syria played a significant role in the decline of agricultural production.

4. Conclusion

Syria is an agriculturally rich country with diverse crops, and the agricultural residues can be utilized for energy generation. This paper identified the distribution of agricultural residues in the Syrian Arab Republic and the total heat value that can be obtained annually from each province. The importance of this paper lies in Syria being an energy-importing country in need of sustainable energy. The total quantity of unused agricultural residues in Syrian lands for 2016 was 1.907 million tons, 698 and 1.213 million tons for field and orchard crops, respectively. The total calorific value obtained was 68.76 gigajoules. Olive, wheat, oranges, and barley accounted for 35%, 11%, 10%, and 7% of agricultural residues, respectively. Aleppo, Lattakia, and Tartous were the top provinces in terms of calorific value production, with percentages of 18.09%, 17.34%, and 11.47%, respectively.

The sustainability of biomass residues, especially in regions cultivating olives, citrus fruits, wheat, and barley, is crucial for choosing and establishing biomass energy stations. Energy can be obtained through pellet or briquette technology from wheat, barley straw, and olive pomace. Corn residues, with their high moisture content, and the pulp resulting from olive processing, are valuable biomass residues for biogas production. In addition to biomass energy conversion methods, utilizing biomass with techniques for biomass use, fertilizer production, construction materials, chipboard production, and the production of bio-based products like bio-plastics are feasible. Obtaining higher value-added biological products and energy with minimal residues in the bio-refinery system is possible. Agricultural residues can be used as inputs for bio-based products in Türkiye. However, regulatory and financial challenges in collecting and transporting agricultural residues, coupled with a lack of public awareness about their use, pose challenges for ensuring economic sustainability and energy security for Syria, which imports most of its energy needs.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	L.G.	G.A.K.G.	M.O.S.E.	B.D.
C	60	20	10	10
D	50	30	10	10
S		80		20
DCP	70	10	10	10
DAI	50	20	10	20
L	25	25	25	25
W	25	25	25	25
CR	20	30	20	30
SR	25	25	25	25
PM	25	25	25	25
FA	25	25	25	25

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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