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BIOFUEL PELLETS AS A SUSTAINABLE ENERGY SOLUTION: EXPLORING THE ROLE OF BIOMASS AND REGIONAL WASTE MANAGEMENT IN TURKIYE'S TR63 REGION

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Abstract: In recent years, the increasing demand for sustainable and renewable energy sources has led to significant interest in biofuels. Bifuel pellets, which combine biomass materials with fossil fuels, have emerged as an innovative and environmentally friendly energy solution. Typically made from agricultural residues, wood waste, or energy crops, blended with fossil fuels such as coal or oil derivatives, bifuel pellets offer improved energy efficiency and combustion properties. By bridging the gap between traditional fossil fuels and renewable energy alternatives, bifuel pellets provide a transitional solution that enhances both calorific value and combustion efficiency. The dual composition of these pellets allows for better adaptation to existing energy infrastructures while supporting reductions in greenhouse gas emissions. In Türkiye, regional development and waste management strategies have been shaped by the adoption of the Nomenclature of Territorial Units for Statistics (NUTS) system since 2002. The TR63 NUTS Level 2 Region, which includes the provinces of Hatay, Kahramanmaraş, and Osmaniye, plays a critical role in agriculture and livestock production. Due to these activities, the region contributes significantly to waste generation. This research highlights the potential of bifuel pellets as a viable energy option for the TR63 Region, where agricultural and livestock residues could serve as essential feedstock for sustainable energy production. The integration of bifuel pellets into regional energy policies could help address environmental goals while reducing dependence on conventional fossil fuels.

Keywords: TR63 region, Biofuel, Pellet, Energy

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1. Introduction

In recent years, the growing demand for sustainable and renewable energy sources has fueled considerable interest in biofuels. Bifuel pellets, an innovative development in this field, represent a versatile and environmentally friendly solution. These pellets are typically composed of biomass materials, such as agricultural residues, wood waste, or energy crops, combined with fossil fuels, such as coal or oil derivatives, to enhance their energy efficiency and combustion properties (Yang et al., 2019; Ståhl et al., 2016). By merging renewable biomass with conventional fuels, bifuel pellets offer a transitional energy solution, bridging the gap between traditional fossil fuels and fully renewable alternatives (Kovač et al., 2021).

The dual composition of biofuel pellets provides several benefits. Biomass, as a renewable resource, is readily available and helps reduce greenhouse gas emissions by absorbing CO_2 during its growth phase, making the combustion of these pellets nearly carbon neutral (Wang et al., 2023). Additionally, the inclusion of fossil fuel components improves the calorific value, combustion efficiency, and stability, making bifuel pellets more adaptable to existing energy infrastructures, particularly for power generation and heating systems (Luo et al., 2010; Karka et al., 2021; Samuelsson et al., 2012).

Biofuel is a type of renewable energy derived from organic materials, known as biomass, including plants, agricultural residues, and waste products. It offers a cleaner alternative to fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable energy sources. Key Types of Biofuels consist of six parts: those are;

Ethanol; Produced from fermentation of sugars or starches. Commonly blended with gasoline.

Biodiesel; Made from vegetable oils, animal fats, or recycled grease. Can be used in diesel engines without modification.

Biogas; Produced from anaerobic digestion of organic waste. Primarily methane and carbon dioxide, used for heating or electricity.

Bioethanol; Similar to ethanol but produced from lignocellulosic biomass like straw or wood.

Biojet fuel; Designed for aviation, derived from oils, fats, or algae. Solid biofuel (Sing et al., 2024).

Biofuel production typically uses biochemical and

thermochemical methods, depending on the feedstock's properties. Biochemical processes like fermentation are ideal for wet biomass, while thermochemical methods like pyrolysis are better suited for dry biomass. Each method has varying costs and efficiencies, requiring tailored approaches for sustainable implementation (Rodionova et al., 2017).

The development of bifuel pellets not only reduces reliance on conventional fossil fuels but also addresses limitations often associated with pure biomass fuels, such as low energy content, moisture sensitivity, and inconsistent quality (Kheshgi et al., 2000). This hybrid fuel offers a practical and economically viable option for both industries and households, providing a cleaner, more efficient energy alternative that supports both environmental and energy security goals (Stattman et al., 2018).

Since 2002, Türkiye has implemented the Nomenclature of Territorial Units for Statistics (NUTS) to collect and develop regional statistics, conduct socio-economic analyses, define regional policy frameworks, and create a comparable statistical database aligned with the European Union's regional statistical system. Türkiye is divided into 12 NUTS Level 1, 26 NUTS Level 2, and 81 NUTS Level 3 regions. The provinces of Hatay, Kahramanmaraş, and Osmaniye, located in the southern part of Türkiye, are defined as the "TR63 NUTS Level 2 Region," within the TR6 Mediterranean NUTS Level 1 Region.

The TR63 Region, located in southern Türkiye, is bordered by the TR62 Adana-Mersin region and the Mediterranean Sea to the west, the TR72 Kayseri, Sivas, Yozgat region to the north, the TRC1 Gaziantep, Kilis, Adıyaman region to the east, and Syria to the south. Covering a total area of 23,607 km^2, the TR63 Region accounts for 3% of Turkiye's total land area. With the enactment of Law No. 6360 on the establishment of metropolitan municipalities in thirteen provinces and the creation of twenty-six new districts, Hatay and Kahramanmaraş gained metropolitan status. There are 32 districts in total: 15 in Hatay, 11 in Kahramanmaraş, and 6 (excluding the central district) in Osmaniye.

Due to its significant role in agriculture and livestock production, the TR63 Region is a major contributor to waste generation (DOGAKA, 2024).

The aim of this study was to determine some agricultural wastes and their waste potential in the TR63 region and to investigate their usability as pellets.

2. Materials and Methods

2.1. Some Materials That Can Be Used for Biofuel in the TR63 Region

The materials identified for potential use as biofuels in the TR63 region include olive pomace, peanut shells, walnut husks, pepper stalk and seed residues, pistachio shells, vineyard pruning waste, forest residues, cotton gin waste, corn residues, barley residues, sunflower residues, wheat residues, and chicken manure.

2.2. Method

Total pellet energy value (TEV) was calculated by multiplying the existing pellet caloric (EPC) value of each product with the total waste potential (TWP). Total energy value is shown in equation 1.

$$TEV=EPC*TWP \quad (1)$$

3. Results

3.1. Properties of Materials and Total Amount of Energy

3.1.1. Olive pomace

Olive residues consist of pomace and wastewater produced during olive oil extraction. Among these, the most important input for energy production is olive pomace. After the olives are pressed to extract olive oil in olive oil factories, the remaining mixture of pits, skins, and pulp is known as olive pomace. The quality of pomace varies depending on the olive oil processing method. The quality of the pomace directly affects the time and cost of processing it for biofuel production.

Table 1. Number and olive pomace production capacity of Olive Oil Facilities in the TR63 Region (TOBB, 2024)

Provinces	Number of Facilities (units)	Production Capacity (tons)
Hatay	28	158,977
Kahramanmaraş	7	26,755
Osmaniye	8	3,500
Total	37	189,232

Looking at the TR63 Region as a whole, this figure averages 189,232 tons per year. Since a significant portion of the olive oil processing facilities operate using a three-phase system, this method has been taken into account when calculating the annual average pomace yield. In this system, 20-25% of olive oil is produced from 100 kg of olives, 45-50% of pomace is obtained, and the remainder is released as wastewater (Hocaoğlu et al, 2015). Therefore, it is possible to obtain an average of 189,232 tons of pomace with a moisture content of 45-55% per year from the region. When olive pomace is produced in pellet form, it generates 4,000-5000 calories/kg of heat (Develi et al., 2021; Miranda et al., 2012). The amount of energy that can be produced from these wastes as pellets is 803 (GJ)/year (Table 2).

3.1.2. Peanut shells

Peanut (Arachis hypogaea) is an annual summer plant belonging to the legume family. It is a highly valuable oilseed crop globally and is recognized as a snack crop in Turkiye. Among the approximately eight oilseed crops used in vegetable oil production worldwide, it ranks among the top three. Its significance lies in its use as both human food and animal feed, as well as its ability to enrich the soil with nitrogen. The composition of peanuts includes approximately 45-55% oil, 20-25% protein, 16-18% carbohydrates, and 5% mineral content.

Peanut shells possess significant potential, with a global production of 6.49 million tons per year and 24.50 000 tons per year in Türkiye. In this regard, peanut shells play an important role among waste plant biomass resources (Taşar et al., 2015). Additionally, peanut production in with a large portion coming from Osmaniye (44 060 tons/year), Hatay (4 411 tons/year), Kahramanmaraş (5 177 tons/year) (TUIK, 2023). The provinces where peanut farming is most prevalent in Türkiye are Osmaniye and Adana, where approximately 88% of the production occurs in the Çukurova region, translating to approximately 200,000 tons/year of production (TUIK, 2023). About 35% of the produced peanuts are generated as waste, which means approximately 70 000 tons of waste is formed annually. In the TR63 region, approximately 54,000 tons of peanuts are produced, resulting in around 19,000 tons of waste. There are 116 peanut processing facilities in Osmaniye, 103 of which are located in the center. Among these 103 facilities, 48 are concentrated in the town of Cevdetiye. The shells remaining after the seeds are extracted from the peanut fruit contain 6-7% crude protein, 1-2% oil, 60-67% crude fiber, 35-45% cellulose, 27-33% lignin, and 2-4% ash. When used as pellets, peanut shell waste produces an average of 4,000-4,300 cal/kg (Moreno et al., 2018). The amount of energy that can be produced from these wastes as pellets is 79 GJ/year (Table 2).

3.1.3. Walnut shells

Türkiye holds a significant position in the global walnut (Juglans regia L.) production landscape. In 2023, Türkiye achieved a walnut production of 360,000 tons per year (TUIK, 2023), placing it fourth in the world for walnut production (FAO, 2023). Kahramanmaraş Province ranks among the top walnut-producing areas in Turkiye, with an annual production of 18,330 tons (TUIK, 2023). Other provinces contribute as follows: Hatay with 2,029 tons/year, and Osmaniye with 1,418 tons/year (TUIK, 2023). The unused outer shell of walnuts accounts for 45% of the waste. In the TR63 region, the total production amount is 21,777 tons per year, resulting in approximately 9,799 tons per year of waste. When walnut shell waste is processed into pellets, it produces an average of 4,000-4500 calories/kg (Kantova et al., 2022). The amount of energy that can be produced from these wastes as pellets is 41 GJ/year (Table 2).

3.1.4. Pepper stems and seed residues

Pepper is a vegetable belonging to the Capsicum genus in the Solanaceae family and is grown as an annual crop in warm climates. In 2023, pepper production figures were as follows: Hatay produced 2,550 tons/year, Kahramanmaraş produced 28,850 tons/year, and the total production in Türkiye is approximately 287,322 tons/year (TUIK, 2023). About 27% of this production occurs in Gaziantep (82,609 tons/year), and approximately 55% of Türkiye's spice pepper production (155,000 tons/year) is sourced from this region. According to information from the Kahramanmaraş Red Pepper Growers Association, around 20% of processed peppers result in waste. Based on this data, the total production of red pepper stems and seeds in the TR63 region amounts to 31,400 tons/year, resulting in approximately 6,280 tons/year of waste. When red pepper stem and seed residues are used as pellets, they generate an average of 3,700-4,000 calories/kg (Başıbüyük et al, 2020). The amount of energy that can be produced from these wastes as pellets is 23 GJ/year (Table 2).

3.1.5. Pistachio shells

Pistachio (*Pistacia vera* L.) belongs to the Anacardiaceae family and is known for its edible, hard-shelled fruit, which comes in 11 different varieties (Zohary, 1952). In 2023, Türkiye's total pistachio production reached 176,000 tons (TUIK, 2023). Approximately 35-40% of the produced pistachios become waste, resulting in about 77,000 to 88,000 tons of waste annually. According to TOBB 2023 data, there are a total of 163 registered pistachio processing facilities in Türkiye, with 64 located in Gaziantep, 1 in Kahramanmaraş and 3 in Osmaniye. Given its proximity to the TR63 region, pistachio shells can be considered an alternative waste resource.

4325 tons of production occurred in Kahramanmaraş and 6 tons in Hatay. The amount of waste that may occur is 2165 tons. When processed into pellets, pistachio shell waste yields an average of 4,100 to 4,300 cal/kg and the waste rate is estimated to be fifty percent (Develi et al, 2021). The amount of energy that can be produced from these wastes as pellets is 8 GJ/year (Table 2).

3.1.6. Vine pruning residues

In the region, with approximately Hatay with about 47,967 decares; Kahramanmaraş with around 114,885 decares and Osmaniye with roughly 1,036 decares of vineyard area (TUIK, 2023). When considering the TR63 region, there is approximately 166,888 hectares of vineyards. In a study by Cavalaglio and Cotana (2007), it was noted that 2.9 tons/ha of vine pruning residues are obtained, while Sanchez et al. (2002) indicated that between 1 to 7.5 tons can be collected per hectare of vineyard. According to a study by Arık (2023), the amount of vine pruning residues is estimated at 3 tons/ha. Thus, the TR63 region generates around 500 664 tons of pruning waste. When collected, the moisture content of pruning residues is around 30-40%, indicating they do not possess excessively high moisture levels. When processed into pellets, vine pruning residues produce an average of 4,000 to 4,300 calories/kg (Akkuş, 2018). The amount of energy that can be produced from these wastes as pellets is 2079 GJ/year (Table 2).

3.1.7. Forest residues

Among biomass resources, forest residues hold significant importance. Biomass that results from the cutting of trees includes fine branches, tops, roots, cones, bark, understory vegetation, and shrub types. In certain Forest Regional Directorates (OBG), woody biomass obtained from forest maintenance and thinning activities is processed into wood chips for particle board

production or prepared for use as fuel in heating systems. The potential of woody biomass available for bioenergy, as estimated by the General Directorate of Forestry (OGM), is approximately 5 million tons annually. The largest potential is concentrated in the western and southern regions, particularly in the Mediterranean Region. In Kahramanmaraş, the production of industrial wood is 219,000 tons, and firewood is 48,000 tons, totaling 267,000 tons. In Hatay, the figures are 229,000 tons of industrial wood and 41,000 tons of firewood, resulting in a total of 260,000 tons. In Osmaniye, industrial wood production stands at 251,000 tons, and firewood at 37,000 tons, giving a total of 288,000 tons of unprocessed wood products (OGM, 2024). The total forest product generation in the TR63 region is estimated to be around 715,000 tons/year. When processed into pellets, forest residues yield an average of 4,350 to 4,850 calories/kg (Özdemir and Er, 2018). The amount of energy that can be produced from these wastes as pellets is 3289 GJ/year (Table 2).

3.1.8. Cotton gin waste

Cotton is sent to ginning factories for the separation of seeds from the cotton fiber. After the ginning process, a substantial amount of waste is generated. The processing waste from cotton, particularly from the ginning and oil production industries, poses significant storage and disposal challenges. In the TR63 region, approximately 280,000 tons of cotton waste is generated. This production consists of 254,000 tons in Hatay, 23,000 tons in Kahramanmaraş and 3,000 tons in Osmaniye (TUIK, 2023). The energy production from ginning waste when used in pellet form is estimated at around 3.900 to 4.250 calories/kg (Karaca and Başçetinçelik, 2010). The amount of energy that can be produced from these wastes as pellets is 1148 GJ/year (Table 2).

3.1.9. Corn residues

The corn generated in 2023 was 175,828 tons in Kahramanmaraş, 210,257 tons in Hatay, 383,067 tons in Osmaniye. The areas used for corn production are approximately 247,080 dekar in Kahramanmaraş, 205,782 dekar in Hatay and 406,296 dekar in Osmaniye. The amount of usable corn waste generated per hectare of corn production has been estimated at 527 kg/dekar (Bascetincelik et al., 2006; Avcıoglu et al., 2019). Based on these figures, the estimated usable corn waste generated in 2023 was around 130,020 tons in Kahramanmaraş, 106,232 tons in Hatay and 211,415 tons in Osmaniye. In total, approximately 448,000 tons of corn waste were produced in the TR63 region. Literature indicates that the calorific value of pellets made from corn residues ranges from 3,817 to 4,287 cal/kg (Özdemir and Er, 2018). The amount of energy that can be produced from these wastes as pellets is 1793 GJ/year (Table 2).

3.1.10. Barley residues

According to TUIK data from 2023, the areas used for barley production are approximately 438,720 dekar in Kahramanmaraş, 33,398 dekar in Hatay and 41,697 dekar in Osmaniye. The amount of usable barley waste generated per hectare has been estimated at 36 kg/dekar (Bascetincelik et al., 2006; Avcıoglu et al., 2019). Based on these estimates, the amount of usable barley waste produced in 2023 was approximately 15,793 tons in Kahramanmaraş, 1,501 tons in Hatay and 1,202 tons in Osmaniye. Overall, about 18,496 tons of barley waste were produced in the TR63 region. The calorific value of pellets made from barley residues is reported to range from 3,600 to 4,100 calories/kg (Serrano et al., 2011). The amount of energy that can be produced from these wastes as pellets is 71 GJ/year (Table 2).

3.1.11. Sunflower residues

According to TUIK data from 2023, sunflower production areas are approximately 85,767 dekar in Kahramanmaraş, 3010 dekar in Hatay, and 87,910 dekar in Osmaniye. The amount of usable sunflower waste generated per hectare is estimated at 550 kg/dekar (Aybek et al., 2015a). Based on this, the estimated usable sunflower waste for 2023 is about 47,171 tons in Kahramanmaraş, 1,655 tons in Hatay, and 48,350 tons in Osmaniye. In total, approximately 97,176 tons of sunflower wastes were produced in the TR63 region. The calorific value of pellets made from sunflower residues ranges from 3,600 to 4,700 calories/kg (Topkoç, 2023). The amount of energy that can be produced from these wastes as pellets is 403GJ/year (Table 2).

3.1.12. Wheat residues

According to TUIK data from 2023, wheat production areas are approximately 879,300 dekar in Kahramanmaraş, 522,370 dekar in Hatay, and 365,398 dekar in Osmaniye. The amount of usable wheat waste generated per hectare is estimated at 37 kg/dekar (Aybek et al., 2015a). Based on this, the estimated usable wheat waste for 2023 is about 32,534 tons in Kahramanmaraş, 19,327 tons in Hatay, and 13,519 tons in Osmaniye. In total, around 65,380 tons of wheat waste were produced in the TR63 region. The calorific value of pellets made from wheat residues ranges from 4,000 to 4,200 calories/kg (Jóvér et al., 2018; Bradna et al., 2016). The amount of energy that can be produced from these wastes as pellets is 273 GJ/year (Table 2).

3.1.13. Chicken manure residues

According to TUIK data from 2023, the total number of meat and egg chickens is approximately 1 568,279 in Kahramanmaraş, 869,273 in Hatay, and 1 124,164 in Osmaniye. Each chicken produces an average of 0.13 kg of waste per day (Aybek et al., 2015b). The total amount of manure generated from chicken waste is approximately 203 tons/day in Kahramanmaraş, 112 tons/day in Hatay, and 146 tons/day in Osmaniye. Overall, the total chicken manure production in the TR63 region is about 461 tons/day and 168, 265 tons. The calorific value of energy produced from chicken manure ranges from 3,100 to 3,500 calories/kg (Özdemir and Er, 2018). The amount of energy that can be produced from these wastes as pellets is 554 GJ/year (Table 2).

3.1.14. Total energy

High potential for energy generation

Forest Residues: With 3,289 GJ, forest residues provide the highest energy potential, making them a leading candidate for biofuel pellet production. Forest residues are widely available, particularly in areas with sustainable forest management, and their high caloric value (4,600 cal/kg) makes them efficient for producing energy-dense pellets. Vine Pruning Waste, Corn Waste, Chicken Manure Residues and Cotton Ginning Waste These materials also stand out due to their considerable mass and substantial energy contributions (2,079 GJ, 1792 GJ, 1521 and 1148 GJ). Those are commonly available in agricultural regions, providing a sustainable means of utilizing otherwise underused residues.

Table 2. Amounts of energy that can be produced from residue TR63 region

Material	Average Material Amount (106 kg)	Average Caloric Value (cal/kg)	Average Energy Amount (GJ)
Olive Pomace	189	4250	803
Peanut Shell Residue	19	4150	79
Walnut Shell Residue	10	4100	41
Pepper Stem and Seed	6	3850	23
Pistachio Shell Residue	2	4200	8
Vine Pruning Waste	501	4150	2079
Forest Residues	715	4600	3289
Cotton Ginning Waste	280	4100	1148
Corn Residues	448	4000	1792
Barley Residues	18	3850	71
Sunflower Residues	97	4150	403
Wheat Residues	65	4200	273
Chicken Manure Residues	168	3300	554
TOTAL	2518		10563

Moderate Energy Contributors

Olive pomace 803 GJ, Sunflower Residues (403 GJ) and Wheat waste (273 GJ), offer decent energy potential. Although their caloric values vary, they are available in significant quantities, making them feasible for biofuel pellet production, especially in regions where these crops and livestock are prevalent. For instance, sunflower residues are a natural by-product of oil production, while corn residues come from large-scale farming operations, and chicken manure addresses waste management challenges in poultry farming. Specialized Residues with Lower Contributions: Peanut Shell Residue, peper stem and seed, Walnut Shell Residue, and Pistachio Shell Residue provide lower overall energy contributions due to their smaller quantities, but they have relatively high caloric values, especially olive pomace (4,250 cal/kg) and pistachio shell (4,200 cal/kg). These residues are most relevant in specific regions where olives, peanuts, walnuts, and pistachios are processed. Their small-scale availability limits their broader application, but they offer valuable localized solutions for biofuel pellet production.

4. Discussion

Celma et al. (2007) used olive and grape wastes in their study in Extremadura, approximately 21,106 tons of waste was obtained from olive waste and 89,106 tons of waste was obtained from grape waste. The amount of energy that could be produced was 369 GJ from grape waste and 89 GJ from olive waste. Moreno et al., 2018, in their study, stated that peanut production in the world is 43,982,066 tons and the average amount of waste that could be generated is 11,000,000 tons. The amount of energy that could be produced from these wastes is calculated as 45,000 GJ on average. Shah et al., 2018, in their study, reported that walnut shells would create 100,000 t of waste in India. The average amount of energy that could be produced from these wastes is 4100 GJ. In addition, a total of 360,000 tons of walnuts were produced in Türkiye in 2023 and 22,000 tons occurred in the TR63 region. 6% of the energy to be produced from these wastes in Türkiye may come from this region (TUIK, 2023). Uzundumlu et al., 2024, Global Pistachio Production Forecasts for 2020–2025, estimated that the amount of Pistachio produced between these years will be 1,078,490 tons and 161,930 tons in Türkiye. This amount is 15% of the amount of Pistachio produced in the world in Türkiye. The amount of waste and energy that may be generated from this product will constitute approximately 15% of the world. In 2023, pepper produced in Türkiye was 287,322 tons and 31,400 tons were produced in the TR63 region. This region constitutes approximately 11% of Türkiye's production. The amount of energy that can be produced from these wastes will constitute approximately 11% of Türkiye's production and has an important place (TUIK, 2023). In a study conducted in 2017, Toklu reported the forest waste that could be generated in Türkiye as 20,000,000 t/year. It is approximately 715,000 tons/year in the TR63 region. This shows that 4% of the energy that can be generated from forest waste in Türkiye can be generated from this region. In 2023, approximately 368,624,420 chickens were raised in Türkiye and 3,561,716 chickens were raised in the TR63 region (TUIK, 2023). The amount of energy that can be generated in this region can constitute 1% of Turkiye. A total of 2,877,000 tons of waste was generated in cotton waste in Türkiye and 279,240 t of waste was generated in the TR63 region

(TUIK, 2023). Approximately 10% of the energy that can be generated from these wastes can be generated from this region. In 2023, corn production was in approximately 9,580,171 decares in Türkiye and 859,159 decares of corn was produced in the TR63 region (TUIK, 2023). This means that 9% of the energy that can be produced from this product in Türkiye can be from this region. In 2023, barley production was in approximately 31,702,723 decares in Türkiye and 513,815 decares in the TR63 region (TUIK, 2023). This means that 1.62% of the energy that can be produced from this product in Türkiye can be from this region. In 2023, sunflower production was in approximately 86,446,679 decares in Türkiye and 151,498 decares of sunflower was produced in the TR63 region (TUIK, 2023). This means that 1.75% of the energy that can be produced from this product in Türkiye can be from this region. In 2023, wheat production was approximately 81,767,068 decares in Türkiye and 151,498 decares of wheat was produced in the TR63 region (TUIK, 2023). This means that 3.2% of the energy that can be produced from this product in Türkiye can be from this region. This study shows that certain agricultural residues, particularly from pistachio, peanut, and olive production, are abundant in the TR63 region of Türkiye. For instance, 6% of walnut waste, 11% of pepper waste, 4% of forest waste, 10% of cotton waste, 9% of corn waste, and 3.2% of wheat waste originate from this region. Due to the sustainability and continuity of these residues, they represent a significant energy resource, with energy potential varying according to waste amounts, as compared to other global studies. The results of this study highlight the importance of agricultural waste in the TR63 region of Türkiye as a significant energy source, particularly from pistachio, peanut, olive, walnut, and pepper residues. With a focus on sustainability, these wastes can contribute to energy production, with energy potential varying by waste amount. Comparisons with global studies show that the TR63 region holds considerable potential for biogas and energy production from agricultural and forest residues, reinforcing the need for strategies to harness these renewable resources efficiently.

5. Conclusion and Suggestions

In conclusion, bifuel pellets represent a promising and innovative solution for addressing Turkiye's energy challenges, particularly in the TR63 region. By integrating biomass materials such as agricultural residues with fossil fuels, these pellets offer a transitional energy source that enhances energy efficiency and reduces greenhouse gas emissions. The TR63 region, characterized by its rich agricultural and livestock production, generates significant amounts of waste, which can be effectively utilized as feedstock for bifuel pellet production.

The diverse range of available materials, including olive pomace, peanut shells, walnut husks, and various crop residues, not only contributes to waste management and environmental sustainability but also enhances the region's energy security. Incorporating bifuel pellets into the regional energy policies aligns with Türkiye's broader environmental goals, promoting the use of renewable resources while reducing reliance on conventional fossil fuels.

Ultimately, the development and implementation of bifuel pellet technology in the TR63 region can lead to a more sustainable energy future, create economic opportunities in biomass processing, and contribute to local job creation. As the demand for renewable energy continues to grow, leveraging the potential of bifuel pellets can play a critical role in advancing Türkiye's transition towards a sustainable and resilient energy system.

In conclusion, this study highlights the significant energy potential of agricultural and forest residues in Türkiye's TR63 region. By utilizing waste from products such as pistachio, peanut, olive, and cotton, substantial amounts of energy can be generated. The TR63 region alone contributes a notable percentage to Türkiye's total energy potential from these wastes. This emphasizes the need for sustainable waste management practices, as increasing waste utilization could enhance energy production and contribute to environmental sustainability in the region.

The study highlights the potential of bifuel pellets as a sustainable energy solution for the TR63 region, emphasizing their role in promoting a sustainable energy future, creating economic opportunities, and generating local employment. To strengthen the impact of the findings, the conclusion could explicitly recommend the following future actions and research directions:

Economic Feasibility and Scalability Studies: Conduct detailed analyses to evaluate the cost-effectiveness and scalability of bifuel pellet production in the TR63 region, ensuring practical implementation.

Policy Recommendations: Develop and advocate for policies that encourage the adoption of bifuel pellet technology, including incentives for producers and users.

Diverse Feedstock Exploration: Investigate alternative feedstock options to broaden the range of materials used for bifuel pellet production, enhancing sustainability and resource utilization.

Pilot Projects: Initiate pilot programs to test and refine bifuel pellet technology on a larger scale, addressing potential challenges and optimizing processes.

Incorporating these suggestions would provide a clear roadmap for advancing bifuel pellet technology and maximizing its benefits for the TR63 region.

Author Contributions

The percentages of the author contributions are presented below. The author reviewed and approved the final version of the manuscript.

	S.Ü.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

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 Statement

The author declare that there is no conflict of interest in this study.

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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