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Review

Possibilities of Using Whey Wastes in Agriculture: Case of Turkey

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Abstract: Liquid wastes are generated during production in the milk and cheese industries. During cheese production, whey emerges as a liquid product. Researchers define waste as raw material instead of waste alone. Hence, there is no doubt that the use and management of waste will gain greater importance in the upcoming years. This study discusses the use of whey, which is food waste, in agriculture and the benefits derived from it in terms of energy value. Our research was based on the current literature and the amount of whey that emerged in the dairy industry. For this purpose, the existing literature was evaluated to determine how much waste was produced from whey. The total amount of whey waste in Turkey for 2021 was determined. Afterwards, the amount of potential energy was determined in evaluating these wastes. Turkey's total amount of potential energy obtained from whey waste was calculated as 570.11×10^6 MJ, with 158.36×10^6 kWh as potential electrical energy. Moreover, it was calculated that a total of 158.36×10^6 kWh of electrical energy would meet the electrical energy of 688,548 families of four people for a month. It is also stated that this potential energy will be used in the field of equivalent electrical energy content and agriculture. It is a fact that cheese wastewater, rich in nutrients and organic matter, can be used in agriculture. Whey is used as animal feed in agricultural fertilization activities and the livestock sector. It has also been understood from the literature that it can also be used in biogas production. However, it should not be forgotten that whey released into rivers, water sources, or sewers threatens the environment due to its high protein content. Therefore, by increasing the number of similar studies on the subject, a wide range of wastes, such as whey, can be utilized in the most accurate manner. As a result, environmental protection, conservation of water resources, and energy conservation can be ensured by properly benefiting from whey waste. Considering that the world population will increase in the future, it is a fact that we will need a cleaner environment and more energy. It was concluded that greater importance should be given to waste management practices for a cleaner environment and energy saving.

Keywords: dairy products; electrical energy; energy conservation; fertilization; organic wastes; sustainable agriculture; wastewater

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1. Introduction

The continuity of life on earth depends on preserving the balance of nature and continuing the cycles of substances such as oxygen, carbon dioxide, water, nitrogen, magnesium, and sulfur, which are essential elements for our existence. All living things in the world continue their lives in their ecosystems. Pollution of materials such as water, air, and soil, which are indispensable for the life of an ecosystem, or disruptions in nitrogen, oxygen, carbon dioxide, and water cycles, negatively affect the life and living conditions of living things in the ecosystem. As humankind's ambition to produce more and accumulate wealth, which evolved with the application of science to production, led to the unintentional consumption of finite natural resources, production and consumer wastes began to damage the world's oceans, rivers, atmosphere, and soils. The increased levels of waste released mean that our ecosystems are becoming damaged even more [1].

The use of fertilizers and pesticides has led to an imbalance between productivity and environmental variables as agricultural activities have become more intensive over the past 50 years, and soil now requires more organic matter. When agricultural wastes are combined with clean technologies and returned to the soil as an organic substrate and valuable materials, damage to the environment and ecosystems is mitigated. These materials can also be disposed of in landfills and utilized as animal feed and as fuel for burning; however, they may have a negative impact on the environment. Agricultural food wastes must be treated, since their microbial decomposition may pose certain potential dangers to the environment [2,3].

Agricultural wastes are defined as wastes left over from the initial stages of agricultural production and the initial processing of raw agricultural products, such as fruits, vegetables, meat, poultry, dairy products, and crops, and can be solid, liquid, or slurry depending on the nature of the agricultural activity. The opportunity for and efficiency of the utilization of these wastes can be evaluated from two different perspectives; the first is the protection of the environment and the improvement of environmental conditions, as the increasing waste problem is the common environmental problem of this century for all countries of the world. The second is that these wastes can be used as precursor raw materials in many sectors in the production of many products, such as biosorbents, fertilizers, and organic molecules [4].

Examining the financial and environmental costs of each system component is vital to achieving sustainable waste management, as is the continued use of the mechanism. A waste management system, which is the most economical and has the lowest operating cost, is a system in which the least amount of waste is produced. In order to reduce the amount of waste, it is necessary to apply techniques that can produce minimum waste and to ensure the recycling of wastes as energy and/or material [4,5]. It was determined in the study by Qian et al. [6] that broiler litter can be used as a sustainable energy source for energy production, and they also reported lower emission values in the combustion system they used. In their modeling studies, Qian et al. [7] developed models for estimating the high heating values of the waste materials formed in poultry houses. These new regression models can be used to predict the high heating value of waste material generated in poultry housing.

Fruits and vegetables are produced in abundance as hotspot agricultural food products. It has immense potential for the reuse of waste, in line with the circular economy concept and with a high impact on quality of life. The waste from these products is valuable for next-generation eco-materials used in the environment, energy, biomedical application, pharmaceutical, and cosmetic industries. Good results were obtained in laboratory-scale experiments using fruit and vegetable wastes as the main agricultural food wastes for the removal of heavy metals and organic pollutants from aqueous solutions, and it was observed that it is possible to apply them at an industrial level in the future. The evaluation of these wastes as eco-materials with adsorbent properties also offers new perspectives for the sustainability of water [3].

Sustainable food management and waste reduction are important problems [1,2,4]. It has been found that almost 30% of the food produced globally is lost and thrown away at some point along the food supply chain (FSC) [8–10], causing serious economic, environmental, and social problems [11–14]. Considering the pollution caused by food waste, the reduction in natural resources, and economic and social damages, effective management and re-evaluation of food waste are the issues that are gaining importance both in Turkey and all over the world for the continuation of sustainable development [1]. The dairy industry is one of the branches of the food industry that is widespread around the world, produces many products such as milk, milk powder, butter, cheese, and ice cream, and has an important share in solid and liquid wastes depending on the production [15,16]. The increase in demand for milk and dairy products in many countries is leading to the massive growth of the global dairy industry [17]. However, rapid industrial growth increases productivity and the spread of toxic substances in soil or water resources [18]. Whey is a liquid by-product from cheese production, which constitutes a large part of the pollution load, especially biological. Whey, which is thrown into the waste system of factories, has a very high pollution load from protein and carbohydrates [18]. Whey is mostly disposed of as a waste product. The challenge for dairy scientists and the industry is to find the best means to use this valuable by-product [19–21]. The main liquid by-product of the dairy industry is whey, which is produced during the production of cheese and casein. Whey contains lipids, carbohydrates, water-soluble vitamins, minerals, and proteins with high biological value [16,22]. Due to its high organic content, wastes from milk production pose a significant threat to the environment [16]. The production process of dairy products generates liquid wastes containing large quantities of chemically modified organics, characterized by high biological oxygen demand (BOD) and high chemical oxygen demand (COD). The dairy industry produces approximately 6–10 L of wastewater by processing one liter of milk [23,24]. Every year, approximately 6–10 L of wastewater and 4–11 million tons of dairy waste are released into the environment globally, posing a serious threat to biodiversity. One of the problems caused by the direct discharge of wastewater into the environment is the consumption of dissolved oxygen. Oils create a film that prevents oxygen transfer on the water surface, thus directing aquatic animals and plants to harsher living conditions [9,23].

As one of the most important production lines for meeting basic human needs, the food industry has a significant environmental impact due to high water use and waste generation. Therefore, recycling food waste due to the nutrients they contain and the potential to be used in producing new products is a particularly important issue. Especially recently, the potential of using food wastes in agriculture within the scope of sustainable agriculture principles has been a subject on which researchers have focused. The aim of the present review study was to reveal the environmental effects of whey waste, considered among dairy industry wastes to have an essential share in human nutrition, and to determine its potential for use in agriculture.

2. Dairy Industry Wastes

Milk contains the nutrients necessary for humans and animals to develop, grow, and remain healthy. This nutrient, holding a prominent place in human life, is one of the rare foods that contain most of the protein, fat, lactose, vitamins, and minerals of animal origin necessary for adequate and balanced nutrition. While milk and dairy products meet the nutritional needs of consumers, they are also effective in preventing osteoporosis, dental caries, obesity, hypertension, colorectal cancer, cardiovascular diseases, and other diseases [25]. Milk is a watery crystal mixture of various salts and milk sugar. Besides colloidal casein and albumin, this mixture has oils in the emulsion [26]. In the dairy industry, raw milk is generally processed into cheese, buttermilk, butter, yogurt, and powdered and condensed milk. It has the highest production in the food sector. The majority of Turkey's milk and dairy production activities are carried out by small businesses established in different regions of the country [27].

The dairy sector shows steady growth in most countries due to the constant increase in demand for milk and dairy products [28]. Global milk production increased by 27% and reached 890 million tons between 2009 and 2019. While the world population increased by approximately 12% between these years, per capita milk consumption increased by 14% and reached an amount equivalent to 117 kg milk^{-1}. When the distribution of milk production by countries in the January–June period of 2020 is examined, the 28 EU states are observed to be in the first place with a production of 82.7 million tons. In this list, Turkey ranks eighth with a production of approximately 5.1 million tons [29]. It is stated that global milk production is increasing in all regions except Africa. It was reported that milk production reached approximately 906 million tons in 2020, an increase of 2.0 percent compared to 2019. Increases in milk volume were highest in Asia, followed by Europe, America, Oceania, Central America, and the Caribbean [30]. The global average per capita milk consumption in 2015–2017 was 111.88 kg, with a 2027 forecast of 179.13 kg considering processed and fresh milk [31,32]. As awareness and specialization among producers in dairy farming in the country have increased, feeding and care conditions have improved, and the number of animals has increased along with yield per animal. The provinces with the highest number of milked cows in 2019 were Konya (352,503 heads), Erzurum (314,897 heads), and Izmir (307,276 heads). In the same year, the highest cow milk production was realized in Konya (1,286,887 tons), Izmir (1,150,838 tons), and Erzurum (937,847 tons), while the highest yield per animal was in Denizli (3830 kg head^{-1} year^{-1}), Tekirdag (3829 kg head^{-1} year^{-1}), and Burdur (3814 kg head^{-1} year^{-1}) provinces [29]. According to Turkish Statistical Institute (TUIK) data, 851,309 tons of cow's milk were collected in June 2022; further, 118,458 tons of drinking milk, 105,699 tons of yogurt, 56,832 tons of cow cheese, 67,656 tons of ayran, and 6895 tons of butter were produced [33].

3. Dairy Industry Waste Sources and Waste Potential

In the dairy industry, raw milk is generally processed into products such as drinking milk, pasteurized or sterilized milk, cheese, yoghurt, buttermilk, butter, etc. Solid and liquid wastes are generated at certain points in the production line of all these products.

The dairy industry waste sources can be listed as follows [34]:

- Wastewater released due to cleaning the remaining products in milk collection tanks, cans, and pipes and other equipment;
- Wastes generated by leakage and overflow because of transport or equipment failure;
- Processing losses;
- Recalled and spoiled products;
- Wastes from by-products such as buttermilk or whey;
- Detergents or chemical compounds used and removed during washing and sanitation;
- Oil and grease wastes released as a result of cleaning operations;
- Wastes generated as a result of the use of toilets, sinks, etc. in the factory;
- Waste elements found in the water used during processing and mixed with the wastewater.

It is possible to examine the dairy industry wastewaters under four groups according to their compositions and origins. These groups are briefly described below [27].

Domestic wastewater is collected from sinks, showers, etc., in the factory. It is similar in composition to urban wastewater and is generally discharged directly to city sewers.

Process waters: in addition to the water produced by the evaporation of milk or whey, they are released from the water used for cooling the milk in special coolers and condensers. These wastewaters generally have a low pollution load and can be discharged after minimum pre-treatment or can be reused with rainwater.

3.1. Cleaning Wastewater

It is generally released as a result of washing and cleaning the equipment that comes into direct contact with milk or dairy products. The pH of the wastewater is affected by the implementation of cleaning-in-place procedures and has less than a 10% effect on BOD and COD loads [27].

3.2. Whey

Whey is a greenish-yellow by-product that remains after the milk is coagulated with any organic acid or rennet during cheese making and the curd is removed by straining [35]. The use of whey is a major concern today [22]. Whey is released as a by-product of the production process and [36–43] can be evaluated as a separate group when collected by separating it from other wastewater streams [27]. Whey is the major by-product of the dairy industry. Disposal without expensive wastewater treatment processes creates an important source of environmental pollution due to its considerable amount and organic load [44].

Although it varies according to cheese-making methods, about 70–90% of the milk used in cheese making passes into whey [35]. It is generally accepted to obtain 9 L of whey in addition to 1 kg of cheese obtained by processing 10 L of milk [43,45,46]. In addition, it is known that an average of 2.5 L of wastewater is released for every 1 L of milk processed [27]. Considering this information, it can be calculated that approximately 215 billion liters of wastewater was released during the processing of 890 million tons of milk worldwide between 2009 and 2019. In addition, worldwide cheese production in 2019 was 23 million tons [29]. Therefore, when calculations are made according to general acceptance, it is seen that approximately 207 million tons of whey are released as a result of worldwide cheese production, according to 2019 data. Furthermore, in Turkey, approximately 10 million tons raw milk was purchased by commercial enterprises in 2021, with an average of 763.3 thousand tons of cheese that was produced [33]. In line with these data, it can be calculated that approximately 9.74 billion liters of dairy industry wastewater and an average of 6.9 million liters of whey would be released in Turkey in 2021. Milk and dairy product factories in Turkey have a major place in terms of pollution load in the food sector. For this reason, these wastes should be treated with the most appropriate treatment methods to avoid disturbing the ecological balance before the wastes produced by these production facilities are discharged to the receiving environment (water and soil) [47]. However, whey, obtained in large quantities and unused, is mostly forced to be released to canals and streams [35]. Due to its high COD content, unevaluable whey is a major environmental problem when discharged into canals, streams, and sewers [48,49]. Therefore, this spread of milk and milk industry wastes and environmental damage also becomes a source of serious health hazards for humans [50]. Wastes from the production of dairy products pose a significant threat to the environment due to their high organic content. Every year, about 4–11 million tons of milk waste is released into the environment globally, posing a serious threat to biodiversity [51]. The main components of whey are water, lactose, peptides, and minerals. It has been revealed in many studies that the protein nitrogen contained in whey is converted to inorganic nitrogen at a rate of 30–60% by microorganisms in the soil, and lactose is an energy source for microorganisms [52,53]. The composition of whey depends on many parameters, such as the composition and quality of the milk processed into cheese, cheese-making technique, the amount and quality of yeast or acid used in coagulation, and coagulation time and temperature. When whey, which cannot be utilized, is discharged to the outside environment, it creates a major environmental issue [48]. Whey often causes control problems for the cheese industry.

4. Waste Load and Environmental Impacts of Dairy Industry Wastes

Sources of waste in the process line should be organized to properly manage the waste generated in the dairy industry [34]. The amount of organic substances, nitrogenous compounds, fatty acids, and oil grease in the composition of the wastes (wastewater and sludge) arising from production in the dairy sector is quite high. In addition to many milk components such as casein, lactose, and inorganic salt in wastewater, detergents, disinfectants, etc., chemicals are also used during cleaning. The high pH, BOD, and COD values can distinguish dairy sector waste and wastewater. Biological oxygen demand (BOD) and chemical oxygen demand (COD) are the most important parameters for dairy industry wastes. Wastewater from cream, cheese, butter, and whey processes in the dairy industry is known as the primary source of BOD. An amount of 1 kg of milk protein has 1.36 kg COD, 1 kg of lactose has 1.13 kg COD, and 1 kg of milk fat has an average of 3 kg COD waste load equivalents. Process points and waste load values of dairy industry wastewater are shown in Table 1 [23].

Table 1. Waste loads of dairy industry wastewater.

Type of Waste	Chemical Oxygen Demand [mg L^{-1}]	Biological Oxygen Demand [mg L^{-1}]	pH	Total Dissolved Solids [L^{-1}]	Total Solids [L^{-1}]
Milk and dairy product factory	10,251.2	4840.6	8.34	8–5802.6	–
Dairy waste	1900–2700	1200–1800	7.2–8.8	500–740	900–1350
Dairy wastewater	2500–3000	1300–1600	7.2–7.5	500–740	900–1350
Whey	71,526	20,000	4.1	22,050	56,782
Pressed whey	80,000–90,000	120,000–135,000	6	8000–11,000	1
Dairy industry wash water	2500–3300	–	6.4–7.1	630–730	1300–1400
Dairy industry wastewater	2100	1040	7–8	1200	2500

Water, soil, and air quality are also affected by this pollution originating from the dairy industry. This may cause climate change and subsequent biological pollution in later stages. Due to the high organic load, the compounds in the milk waste break down rapidly as it flows down the drain, resulting in the depletion of dissolved oxygen. Such bodies of water are breeding grounds for pathogens that cause dangerous diseases (malaria, yellow fever, etc.). It can also facilitate the spread of insects and various rodents. Low sludge settlement ability brings various operational challenges in biological treatment plants such as oxygen consumption and low process efficiency. In addition, intense concentrations and high levels of compounds from dairy effluents can be toxic to fish and certain algae species. It can also change the physical and chemical composition of the soil [16].

5. Whey Waste

Whey, a side-product of the cheese industry, has a high organic content and is suitable for anaerobic treatment. However, due to its high biodegradability, it tends to have low bicarbonate alkalinity and high acidity. Whey is an important by-product that contains serum proteins from milk components and varying levels of lactose, fat, mineral substances, and proteins and is formed as a result of filtration during cheese making [49]. The treatment of wastewater from cheese factories, especially whey, is carried out by physico-chemical and/or biological methods. However, the cost of physico-chemical methods is higher, and the cost of removal of soluble COD is low. For this reason, anaerobic digestion and biological methods are preferred for the removal of organic loads [16,50]. Depending on the precipitation method of casein in production, two types of whey are formed: sweet and acidic (pH < 5) [46,53]. According to the production method and the coagulation of casein, whey is divided into two groups: acidic whey with pH < 5 and sweet whey with pH 6–7 [16,22]. The composition of whey varies depending on factors such as the quality and type of milk used, the method used in production, and the acid or enzyme formation of the material used for coagulation. In general, 93–94% of whey is composed of water, while a majority of the remaining part of whey is lactose, and the remaining part is composed of protein and fats [46]. Some cheeses are made by coagulating milk with rennet, which accounts for about 75% of global cheese production (sweet whey). The remaining 25% is cheeses obtained by coagulating milk with harmless organic acids (acid whey) [54]. Table 2 shows the data on the composition of whey [55–57]. Whey's proximate and ultimate values are given in Table 3 [58].

Table 2. Typical composition of whey.

Components	Sweet Whey [g L^{-1}]	Acid Whey [g L^{-1}]
Total solids	63–70	63–70
Lactose	46–52	44–46
Proteins	6−10	6–8
Calcium	0.4–0.6	1.2–1.6
Phosphate	1.0–3.0	2.0–4.5
Lactate	2.0	6.4
Chloride	1.1	1.1

Table 3. Proximate, ultimate, and COD analysis of whey.

Parameters	Whey
Moisture (%)	91.4
TS (%)	8.6
VS (%)	85.8
VS/TS (%)	10
COD (mg L^{-1})	122,000
C (%)	NA
N (%)	NA
C/N	NA
O (%)	NA
S (%)	NA
H (%)	NA

Organic components in whey, with biological oxygen needs ranging between 39,000–48,000 ppm, are the main sources of pollution. The organic substances in question cause eutrophication, negatively affecting the living conditions of aquatic organisms and causing mass deaths, especially by reducing the dissolved oxygen level in the water, which is essential for fish. In addition, it encourages the development of some poisonous plant and algae species by causing the spread of toxic substances in the water.

In summary, a dairy enterprise that uses 10 tons of milk in cheese production and releases approximately 8 tons of whey without purification causes environmental pollution comparable with that of a city with a population of 8000. Countries that are developed in the dairy sector and are conscious of environmental problems and the protection of nature use whey in producing many by-products (ethyl alcohol production, lactose production, feed industry, pharmaceutical sector, etc.) [55,56]. It is possible to treat, recycle, reuse, or utilize agricultural wastewater from the dairy industry. Moreover, since there are milk components in these wastewaters, it is advised that casein production is carried out [59]. Researchers have reported that non-alcoholic and alcoholic beverages contain casein whey [44,57]. Alapitvany [60] stated that whey, as an important dairy waste, has a wide variety of uses in agriculture, food, medicine, and the chemical and cosmetic industries as well as in energy production.

6. Agricultural Usability of Whey Waste

Whey can be used in agricultural lands as a food and water source to support plant growth [28]. Studies have reported that if organic waste from the food industry is spread on agricultural fields as fertilizer, it improves plant nutrient flow [44]. An amount of 3700 L of whey used for this purpose contains approximately 36 kg of $(NH_4)_2SO_4$, 12 kg of superphosphate, 6.8 kg of $CaCO_3$, and 5.9 kg of K_2SO_4 mineral substance. Whey can also be used as irrigation water in slightly alkaline and near-neutral soils. It was reported that whey applied to acidic soils triggers soil compaction and prevents the increase in soil microorganisms that decompose the added nutrients [28].

It was observed that spraying whey on barley prevented the spread of a virus species from the plant surface, and spraying whey on tomato leaves for six days considerably reduced the activity of mosaic virus [60]. It was set forth by researchers that positive results have been obtained in tomato cultures by adding dry whey to the compost mixture [61–63]. Whey can be used as irrigation water in agriculture when diluted 1/20 with clean water. It was also indicated that whey has fertilizer properties on acidic soil in regions exposed to heavy rainfall throughout the year.

In a former study, it was calculated that every 3 tons of whey applied on the field provides plants with nutrients equivalent to 1 ton of farm manure and that the aforementioned method has a positive impact on soil structure in addition to being economical [64]. Another study stated that up to 25 tons of whey can be used easily for 0.1 hectares of land. It was reported that 1 ton of whey used on a pasture or field provides about 1.5 kg of K, 1.5 kg of N, and 0.4 kg of P despite small amounts of Na, Ca, Cl, and Mg elements released to the soil [65]. An increase in productivity was observed in a study conducted in Poland by irrigating plants with 3000–7000 m^3 whey or by spraying 1000–1500 m^3 of whey per hectare of land [66]. It was determined that using whey in corn production increases the product amount and has positive impacts on soil porosity [67]. It was determined in another study that 70 kg of K, 68 kg of N, 53 kg of Ca, 50 kg of S, 30 kg of P, 20 kg of Na, and 5 kg of Mg would be obtained per hectare of land by applying 4.5 tons of whey to one hectare of agricultural land [68].

In a study conducted in Turkey, researchers produced a new fertilizer by combining whey with Arbuscular Mycorrhizal Fungus (AMF) living in plant roots. It was stated that this fertilizer positively affects soil properties and plant growth, thus increasing product productivity by approximately 30–40% [69]. There are also many studies on the use of whey in livestock [18–20,70]. It was observed that the rate of digesting dry matter components of animals increased due to softening of the dry grass used in animal nutrition with whey instead of water. It was also reported that mixing the feed with 5% whey increases the animal's utilization of phosphorus and protein [60]. Some examples of whey applications in agriculture are shown in Table 4.

Table 4. Examples of the use of whey in different crops.

Crop Type/Treatment	Impact of Whey Use	Reference
Wheat (*Triticum aestivum* L.)	inhibitory effect on seeds germination in the germination stage	Grosu et al. [42]
Soy (*Glicine max* (L) *Merr*)	superior development compared with control samples	Grosu et al. [42]
Broccoli (*Brassica oleracea* var. *italica* Plenck)	positive influence on the biosynthesis and the accumulation of active principles from plants	Grosu et al. [42]
Barley (*Hordeum vulgare* L.)	prevented the spread of a virus species from the plant surface	Alapitvany [60]
Corn (*Zea mays* L.)	increased the product amount	Watson et al. [67]
Tomato (cultivars 'Roma' and 'Rio Grande')	cheese whey wastewater presented plant growth factors	Prazeres et al. [70]
Addition of whey-based hydrogel to soil	positive effect on water retention and basic soil properties	Čechmánková et al. [71]
Chickpea (*Cicer arietinum* L.)	increased nodulation, root colonization, the nutrient content of seeds, yield, and yield components	Erman et al. [72]
Addition of whey powder to soil	significant increase in microbial biomass C, soil respiration, dehydrogenase activity, and catalase activity in soil	Akay and Sert. [73]
Addition of acid whey-based hydrogel to soil	enhanced the quality of soil	Durpekova et al. [74]

As Table 4 indicates, a study conducted by Grosu et al. [42] concluded that the early outcomes of thin-layer chromatography (TLC) and UV-VIS spectroscopy analyses of the extracts do confirm the positive influence of whey on plant development, thus paving the way for additional research. Another study conducted by Prazeres et al. [70] applied NaOH precipitation to cheese whey wastewater (CWW) and reported a pH range of 8.5–12.5. A pH level of 11.0 was observed to yield optimum results. Significant levels of reduction were observed in chemical oxygen demand, COD (40%); turbidity, T (91%); total suspended solids, TSSs (69%); sulfates (93%); phosphorus (53%); total hardness (40%); calcium (50%); magnesium (27%); chlorides (12%); and Kjeldahl nitrogen (23%). Čechmánková et al. [71] achieved findings that indicated positive impacts on water retention and basic soil properties after introducing different levels of hydrogel to soil. Adding a whey-based hydrogel usually increases the available nutrient concentration and water retention in soil. According to Erman et al. [72], when whey is combined with AMF, it significantly increases root colonization, but combining it with Rhizobium has an increasing effect on the number of nodules. It was observed that combining two or more treatment methods yields more effective results than singular applications. The combination of all three treatments provided the greatest yield, root colonization, and nodulation under irrigation. Akay and Sert [73] observed that whey positively impacts the biological properties of soil. It can be concluded that whey, due to its high nutrient element content, can be fit for use in fertilization practices, particularly as a nitrogen source. There is still room for multi-perspective studies on this topic. According to Durpekova et al. [74], the obtained results indicate the potential of the hydrogel to enhance the quality of soil, as well as reveal how acidic whey can be utilized in the development of a soil-conditioning agent and nutrient-release products.

7. Utilization of Whey Waste in the Energy Field

The need for energy and resources has increased due to rapid population growth and technological developments worldwide. As a result, many nations throughout the world are concerned about how the increased usage of traditional energy sources such as coal and oil-which are easily accessible and clean-is contributing to a variety of environmental issues, such as air pollution and global warming [75]. Energy is used directly in all mechanical systems in agricultural production on Earth. However, to prevent environmental problems arising from using conventional fuels, renewable energy sources should be preferred in the realization of agricultural activities [76].

Whey is currently used directly as animal feed, processed for human consumption, or used as field manure. However, using whey in energy production is not common [77,78]. The fact that whey is rich in carbohydrates in terms of content makes it an economical option in hydrogen gas production [18,60]. The use of biogas produced by anaerobic digestion of wastewater is an application that is increasingly used to generate electricity. This practice also provides environmental and economic benefits [44,79,80]. As a result of anaerobic fermentation, hydrogen can be obtained from whey. In the process in question, it is possible to obtain 8 moles of hydrogen from approximately 1 mole of lactose. There are also carbon dioxide and methane gases in this biogas mixture. However, due to its high lactose content, whey, a suitable raw material for biological processes, causes significant problems in anaerobic systems in its untreated form. Because of the separation of high organic compounds and lactose in its content, whey has low alkalinity. By applying the necessary degrees of dilution, initiating fermentation events, and adding alkaline chemicals, whey can be rendered acceptable for the procedure [60].

Although there are many options for the evaluation of whey, approximately half of the whey produced worldwide is discharged to the receiving environment without any treatment [47,80]. Since nitrogen in whey dissolves in water, it can mix with groundwater and thus affect human and animal health negatively. Furthermore, continuous discharge to the land deteriorates the chemical and physical structure of the soil, reduces crop yield, and causes significant water pollution problems [81]. For this reason, whey must be purified by applying anaerobic treatment and then discharged into receiving environments following aerobic purification. Thus, biogas, a by-product of anaerobic treatment, is obtained while preventing whey-based environmental pollution. Furthermore, the obtained biogas can be used to meet some of the energy requirements in the production part of the dairy industry, which is high due to its high methane content, so it can play a role in reducing the cost [82]. Whey is separated anaerobically for biogas production. At this stage, it is necessary to first talk about anaerobic treatment. Anaerobic treatment is a process in which organic materials are converted into inorganic substances such as methane (CH_4), CO_2, and ammonia in an oxygen-free environment. Anaerobic degradation of biodegradable organic materials is a treatment method performed by different bacterial groups [83].

Kavacık and Topaloğlu [49] investigated the daily amount of whey and various mixtures of cow manure at different temperatures and with methane production, chemical oxygen removal, total solids, and volatile fatty acids. The researchers studied two different dry matter ratios (8% and 10%). The hydraulic waiting time was set to 5, 10, and 20 days. Decomposition efficiency and biogas production amount were calculated for each hydraulic residence time. It was reported that the highest biogas production was obtained with 8% dry matter at 34 °C and 1510 m^3 m^{-3} per day in a 5-day hydraulic holding period.

In another study, Ghaly and Kamal [83] used a mixture of whey and fertilizer in a two-phase generator. The generator operated at 25 °C and 35 °C for 10-, 15-, and 20-day standby times. Whey was tested as pH controlled and uncontrolled. As a result, the highest biogas production was obtained in pH-controlled experiments. It was observed in the aforementioned study that biogas production increased with temperature but that the methane ratio was around 60%, displaying little change in this ratio. The highest biogas productions were found to be 83.7 L of biogas per gram of dry organic matter at 25 °C with a waiting time of ten days and 156.55 L of biogas at 35 °C. Biogas energy can be used as fuel for heating, lighting, and starting gasoline-powered engines [84]. Other purposes of biogas plants, the main purposes of which are to produce electricity and heat energy without harming the environment, are to ensure the controlled storage of wastes, to create a purification effect, to minimize the odor problem, and to encourage the use of organic fertilizers. According to some research, depending on the qualities of the soil and the type of plant grown, fermented manure enhances the yield by 10% to 30% in comparison to unfermented manure [85]. The potential energy value of the resulting whey can be calculated. When calculating the energy equivalent of whey, according to Gillies [65], approximately 1.5 kg N, 0.4 kg P, and 1.5 kg K values of 1 ton of whey to soil are taken into account. N, P, and K energy equivalents are 60.60 MJ kg^{-1}, 11.10 MJ kg^{-1}, and 6.70 MJ kg^{-1}, respectively [86,87]. The energy equivalent of 1 ton of whey is shown in Table 5.

Table 5. The energy equivalent of whey.

Components	Amount [kg]	MJ kg^{-1}	Total Energy [MJ]
N	1.5	60.60	90.90
P	0.4	11.10	4.44
K	1.5	6.70	10.05
	Total		105.39

According to Table 5, using N, P, and K energy equivalents, the energy equivalent of 1 ton of whey was calculated as 105.39 MJ ton^{-1}. According to the data of the Turkish Statistical Institute (Table 6), there was 1100615 tons of whey and buttermilk waste in Turkey in 2021 [33]. TUIK data were individually studied and are shown in Table 6. In the calculation, whey is taken as 7.4 MJ kg^{-1} dry matter [88]. According to the average composition of whey, approximately 93% of it contains water [89,90]. Based on these explanations, 7% of whey is included in the calculation as dry matter. Thus, the energy equivalency calculation that can be obtained from whey is illustrated in Table 7.

Table 6. Turkey's milk and dairy product production in 2021 [33].

Assortment	Production [tons]
Full-fat drinking milk	778,522
Lactose (milk sugar)	0
Pasteurized full-fat drinking milk	88,147
Sterilized full-fat drinking milk	0
Uht full-fat drinking milk	690,375
Lactalbumin	0
Sheep milk	28,609
Goat milk	45,762
Buffalo milk	3168
Semi-skimmed drinking milk	644,020
Pasteurized semi-skimmed drinking milk	2864
Sterilized semi-skimmed drinking milk	0
Uht semi-skimmed drinking milk	641,156
Non-fat drinking milk	58,522
Pasteurized skimmed drinking milk	0
Sterilized skimmed drinking milk	0
Uht skimmed drinking milk	58,522
Skimmings	41,129
Skimmings fat content ≤ 29%	853
Skimmings fat content > 29%	40,277
Milk powder	126,500
Full milk powder	39,225
Semi-skimmed milk powder	1597
Skimmed milk powder	85,678
Cream milk powder	0
Other powder products	0
Cheese (by dairy category)	754,830
Cheese only from cow's milk	728,777
Cheese only from sheep's milk	1016
Cheese only from goat's milk	236
Cheese only from buffalo's milk	159
Cheese from mixed (blended) milk	24,642
Cheese (made from all milk)	754,830
Soft cheeses	94,527
Medium soft cheeses	246,577
Hard cheeses	146,534
Medium-hard cheeses	252,391
Extra hard cheeses	9030
Cheeses made from curdled milk	5772
Whey and buttermilk	1,100,615
In liquid form	1,047,105
Concentrated	0
In powder or block form	53,510
Casein and caseinates	0

Table 7. The energy equivalent of total whey.

Amount [ton]	Dry Feedstock [7%]	Dry Feedstock [MJ ton^{-1}]	Total Energy [MJ]	Total Electricity Energy [kWh]
1,100,615	77,043.05	7400	570,118,570	158,366,269

Table 7 shows Turkey's total amount of potential energy obtained from whey waste, which was calculated as 570.11×10^6 MJ, and the potential electrical energy calculated as 158.36×10^6 kWh. Reference information was used to convert MJ energy to kWh electricity (1 kWh = 3.6 MJ) energy [91].

The monthly average energy consumption of a family of four is 230 kWh [92]. Moreover, it was calculated that a total of 158.36×10^6 kWh of electrical energy can meet the electrical energy of 688,548 families of four people for one month. Additionally, the potential heating energy content that can be obtained from whey was calculated. The total potential heating energy content that can be obtained was calculated as 540.36 × 10^9 BTU. In a study conducted by Sözer and Yaldız [48], it was stated that the highest biogas production was obtained from a mixture of 50% cattle manure and 50% whey. It was emphasized that adding 50% whey increased biogas production by 2.23 times. According to 2021 data obtained from the Turkish Statistical Institute, the number of cattle in Turkey is 18,036,117 [33]. One head of cattle produces 3.6 tons of wet manure per year. Therefore, 33 m^3 of biogas is produced from 1 ton of cattle manure [93,94]. Because the cattle spend most of the day in the barn, it was claimed that only 50% of the manure produced was recovered [48]. Approximately 21% of this manure is dry matter [48,95]. According to this information, the annual amount of manure as dry matter obtained from a total of 18,036,117 cattle in Turkey is 6,817,652 tons. Afacan and Kasap [94], state the energy equivalent of 1 m^3 of biogas as 5100 kcal m^{-3} [96]. In the calculation, 860 kcal is taken as 1 kWh [97], and 1 TWh is taken as 10^9 kWh [98]. The energy equivalent of biogas production is shown in Table 8.

Table 8. Potential electricity generation from biogas.

Dry Manure [tons]	m^3	Biogas Production [m^3]	Total Energy [kcal]	Total Electrical Energy Value [kWh]
6,817,652	33	224,982,516	1,147,410,831,600	1,334,198,641

According to Table 8, the total potential biogas production is 224.9 × 10^6 m^3, the total potential energy equivalent is calculated as 1.14 × 10^{12} kcal, and the potential electrical energy equivalent is 1.33 × 10^9 kWh. According to Sözer and Yaldız [48], the total amount of biogas that can be produced by mixing 6.81 × 10^6 tons of whey with 6.81 × 10^6 tons of fertilizer increases by a factor of 2.23. In this context, 501.7 × 10^6 m^3 of total potential biogas can be obtained, and 2.97 × 10^9 kWh (2.97 TWh) of potential electrical energy can be produced. Therefore, the potential electrical energy values obtained from cheese wastewater can be used in houses and agricultural areas. Biogas can be an alternative to overcome the energy deficit in Turkey, protecting the national capital and preventing greenhouse gas emissions into the atmosphere. Manure should be considered an energy source, not a waste [94]. Processing organic wastes with biogas technology is an alternative to prevent pollution caused by these wastes and to obtain energy in an environmentally friendly manner. Biogas technology can play an essential role in reducing the environmental pollution caused by fossil-based energy sources, as well as the dependence on these sources. Therefore, it is necessary to open and expand such facilities and benefit from clean energy sources more effectively and intensively [48].

8. Discussion

According to FAO, approximately 1.3 billion tons of food is produced annually for human consumption in the world. In other words, 190 kg of food per person is thrown away every year. Considering the pollution caused by food waste, the reduction in natural resources, and the economic and social damages, effective management and re-evaluation of food waste is an important issue for the continuation of sustainable development [11,99]. The innovations brought about by globalization have resulted in changing consumption habits and waste of resources with the increasing population. While there are more than 800 million starving people in the world, it is disturbing to consider that much of the food produced for human use is wasted before it is even consumed [100,101]. Large amounts of food waste, called by-products, are formed due to processes in food factories. Most of them are either destroyed immediately (a large part of which causes environmental pollution) or are used to produce products with low economic value (animal feed, fertilizer, etc.) [102,103]. Food waste is a significant issue that has recently gained attention for this reason [102]. Regarding the amount of organic matter, minerals, and nutrients they contain, the wastes produced by the dairy sector become more significant. Particularly in the culinary, pharmaceutical, agricultural, and energy industries, whey is a significant waste. There are studies on the utilization of whey in many agricultural fields. According to these studies, it is used for the prevention of the use of fertilizers, the generation of biogas, the manufacture of animal feed, and even the prevention of some plant diseases [18,20,78]. Additionally, whey and animal manure combinations can be used for biogas experiments. The usage of whey in the food industry and its economic implications are expanding daily. In addition, whey that has not been processed is just dumped in the natural environment. Whey is a type of highly concentrated effluent that has a high COD and BOD, a low pH, and low alkalinity [104–106]. A total of 9 L of whey is produced from 1 kg of cheese [44,107,108]. Such a significant waste quantity needs to be assessed across several disciplines. This analysis is crucial since it safeguards changes in the environment, nature, and energy. It is predicted that there will be more than 9 billion people on the planet by 2050. As a result, there will be simultaneous increases in consumption and dietary needs. Analyzing whey, which is considered to be waste in this context, is crucial for nature and the environment because wastes result from consumption. For the good of the environment and a sustainable economy, it may be beneficial to recover the components of whey and/or use whey as a fermentation medium. The study specifically looked at the applicability of whey in the agricultural sector. Much of whey is being utilized and will be used in the field, according to researchers. Anaerobic treatment has a significant positive impact on a nation's economy since the wastes from the dairy and cheese industries are highly organic [49]. Whey, a by-product of the dairy industry, can be treated anaerobically since it contains a lot of organic materials. Additionally, whey can be used to make biogas. Therefore, by transforming the energy that is produced from biogas into equal electrical energy, agricultural firms can lower their electricity expenses. Of course, it is also necessary to consider whether this is economically feasible. Whey is believed to be useful in many agricultural processes in this context if we treat each waste as a raw material rather than a waste. In summary, whey is a lucrative by-product in the agriculture sector with a variety of uses in the food and pharmaceutical industries.

9. Conclusions

Due to its high protein content, whey, one of the by-products produced by the dairy industry, can be hazardous to the environment, water supplies, and land if it is not properly stored and utilized. Whey from the manufacture of cheese is dumped into sewage systems and water supplies, particularly in Turkey. Whey released into water supplies in this manner depletes oxygen levels and makes the lives of aquatic beings difficult. Small businesses make up the majority of the dairy sector players in Turkey. As a result, it is very financially challenging for these businesses to build treatment plants. In this regard, evaluating whey in many agricultural domains is crucial. The combined enterprises that include both plant and livestock enterprises make up 68% of the agricultural enterprises in our nation. Turkey must therefore assess and properly dispose of whey used in the manufacturing of cheese in both plant and animal production facilities. The amount of whey that would arise in Turkey in 2021 was calculated in this study. These determined values were used to calculate potential electrical energy amounts. The equivalent quantity of energy that can be used in residential areas was calculated and can be used in agriculture using the calculated potential electrical energy. The estimated quantity of electrical energy in whey is 158.36×10^6 kWh. In light of this, it was determined that the monthly electricity needs of 688,548 families may be satisfied using the example of a family of four. Once more, 2.23 times as much biogas can be produced with the same amount of whey to enhance the amount of biogas produced from animal dung. As a result, more electrical energy can be generated in theory. Waste from the dairy business is still a major issue. It is recommended that further research and academic studies be conducted to better utilize whey, a significant by-product of the dairy sector in agriculture. It follows that whey, which is rich in organic materials and a significant waste in terms of content, can be utilized in a variety of agricultural fields. At the same time, the utilization of whey can lead to the production of biogas, bioethanol, electricity, etc. Utilizing renewable energy instead of non-renewable energy can help create a cleaner environment through energy consumption. Reduced garbage can also lessen negative effects on the environment and nature. Therefore, land and water resources can be safeguarded if the indiscriminate release of whey to the outer environment is avoided. Additionally, water may be saved, its usage in agriculture can be enhanced, and energy production can be highlighted.

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