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Manure management practices and biogas potential assessment in dairy cattle farms in Samsun province, Türkiye

Prácticas de gestión del estiércol y evaluación del potencial de biogás en granjas de ganado lechero en la provincia de Samsun, Türkiye

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ABSTRACT

Despite the expansion of the livestock sector in Türkiye, manure management in dairy farms has not yet reached the desired level of modernization, and manure is still not utilized according to its full environmental and economic potential. This issue is particularly important in Samsun province, where livestock production is intensive and ineffective manure handling may increase environmental pressure, reduce farm efficiency, and compromise hygiene and animal welfare. This study aimed to analyse manure management practices in dairy cattle farms in Samsun province, Türkiye, in terms of structural, technical, economic, environmental, and animal welfare dimensions. Data were obtained from 77 dairy cattle farms through face-to-face questionnaires administered to members of the Cattle Breeders' Association. Descriptive and comparative analyses were conducted, and the annual biogas and electricity generation potential was estimated using accepted conversion coefficients. The findings showed that most farms manage manure using traditional manual methods and lack adequate storage and mechanization facilities. Open-yard manure storage was the most common practice (42.9 %), whereas only 9.1 % of the farms had a sealed manure pit and 10.4 % reported having no designated storage area. The estimated total fresh manure production was 3.80 million tons per year, corresponding to 12.71 million m³ of biogas and approximately 59.75 gigawatt-hour of electricity. Despite this substantial potential, low awareness, inadequate infrastructure, and limited financial support remain major constraints. The study concludes that improving manure management systems through farmer training, cooperative biogas investments, and regulatory practices may enhance environmental sustainability, animal welfare, and the overall economic efficiency of dairy production in the region.

Key words: Manure management; dairy cattle farms; biogas potential; economic efficiency; environmental sustainability.

RESUMEN

A pesar del crecimiento del sector pecuario en Turquía, la gestión del estiércol en las explotaciones lecheras todavía no ha alcanzado el nivel deseado de modernización, y este recurso sigue sin aprovecharse plenamente en términos ambientales y económicos. Esta situación es particularmente relevante en la provincia de Samsun, donde la producción pecuaria es intensiva y un manejo inadecuado del estiércol puede incrementar la presión ambiental, disminuir la eficiencia productiva y comprometer la higiene y el bienestar animal. El objetivo de este estudio fue analizar las prácticas de gestión del estiércol en explotaciones de ganado lechero de la provincia de Samsun, Turquía, desde las dimensiones estructural, técnica, económica, ambiental y de bienestar animal. Los datos se obtuvieron de 77 explotaciones lecheras mediante encuestas presenciales aplicadas a miembros de la Asociación de Criadores de Ganado Bovino. Se realizaron análisis descriptivos y comparativos, y se estimó el potencial anual de producción de biogás y generación de electricidad utilizando coeficientes de conversión aceptados. Los resultados mostraron que la mayoría de las explotaciones maneja el estiércol mediante métodos manuales tradicionales y carece de infraestructura adecuada para almacenamiento y mecanización. El almacenamiento en pilas a cielo abierto fue la práctica más común (42.9 %), mientras que solo el 9.1 % de las explotaciones contaba con una fosa de estiércol sellada y el 10.4 % indicó no disponer de un área de almacenamiento designada. La producción total estimada de estiércol fresco fue de 3.80 millones de toneladas por año, lo que corresponde a 12.71 millones de m³ de biogás y aproximadamente 59.75 gigavatio-hora de electricidad. A pesar de este importante potencial, la baja concienciación, la infraestructura insuficiente y el apoyo financiero limitado continúan siendo restricciones relevantes. Se concluye que el fortalecimiento de los sistemas de gestión del estiércol mediante capacitación a los productores, inversiones cooperativas en biogás y medidas regulatorias puede contribuir a mejorar la sostenibilidad ambiental, el bienestar animal y la eficiencia económica global de la producción lechera en la región.

Palabras clave: Gestión del estiércol; explotaciones de ganado lechero; potencial de biogás; eficiencia económica; sostenibilidad medioambiental.

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INTRODUCTION

With the continuous increase in the global population, meeting the growing demand for protein of animal origin has made intensive livestock production increasingly inevitable. As a result, effective management of manure produced in the dairy cattle (*Bos taurus*) sector has become critical for both environmental sustainability and economic returns [1].

Manure management is a key part of nutrient cycling in livestock systems. Using manure well is needed to reduce losses to the environment [2]. Manure practices also matter for climate change. The Intergovernmental Panel on Climate Change (IPCC) reports that manure management accounts for about 0.7 % of global greenhouse gas emissions, mainly nitrous oxide and methane [3]. For this reason, manure processing and storage are often included in emission reduction plans [4].

Many countries have manure policies to reduce environmental impacts and to turn manure into a product with added value. In the European Union, the annual limit for livestock-derived nitrogen applied to agricultural land is 170 kg per hectare, to reduce groundwater pollution from excessive manure use [5]. In the United States, the Environmental Protection Agency (EPA) requires Concentrated Animal Feeding Operations (CAFOs) to obtain permits under the Clean Water Act and to manage manure so that water resources are not harmed [6].

Also in 2016, the State of California passed a law aiming to reduce methane emissions from dairy operations by 40 % by 2030 and allocated a fund of 260 million USD to reduce liquid manure storage systems on farms and support biogas plants. Through such policies and incentives, improvements in manure management practices are actively pursued [7].

Although the livestock sector in Türkiye has expanded rapidly to meet the demand for animal protein from a growing population, it has not yet reached the desired level of modernization in manure management. Studies conducted in different regions of the country show that the manure produced in dairy cattle farms is largely managed by traditional methods and its potential is not sufficiently utilized. According to the Turkish Statistical Institute (TÜİK), the national cattle population in 2024 is recorded as 16.824 million cattle [8].

This level of animal density results in the production of millions of tons of manure each year, which, if not properly managed, can put significant pressure on the environment. In this context, the main objectives of effective manure management on dairy farms are to protect animal health by maintaining hygienic conditions, minimize water and air pollution, reduce odor and pollution, control pest populations and balance fixed investments, operating costs, labor and nutrient use in accordance with current regulations [9, 10, 11].

Samsun province, which is characterized by different climatic conditions and strong agricultural potential, is among the regions in the Black Sea region where livestock production is particularly intensive. It ranks 11th in Türkiye in terms of bovine livestock and has an important position in cattle, buffalo, sheep and goat breeding [12].

This study aims to analyze the structural, technical, economic and environmental dimensions of manure management in dairy cattle farms in the province of Samsun using a holistic approach. Commenting on the effects of current management practices on animal welfare, this research aims to develop improvement strategies at the farm level and to create a data-based guide for livestock policies.

MATERIALS AND METHODS

The primary material for this research comprises data collected through a face-to-face survey with dairy farm owners who are members of the Cattle Breeders' Association in Samsun Province, specifically in the districts of Alaçam, Kavak, Bafra, Çarşamba, Tekkeköy, Terme, Havza, and Ladik, where dairy farming is most prevalent. The selected enterprises were visited and the questionnaires were filled in through direct interviews.

The responses of the respondents were transferred to a digital format to create the study dataset and then analyzed using statistical methods. During the assessment, the socio-economic and demographic characteristics of the respondents were first identified, and the questionnaire responses were interpreted in relation to these characteristics in order to address the main objectives of the study.

The number of enterprises included in the study were determined using a stratified random sampling approach. With 10 % margin of error and 90 % confidence level, the required sample size was calculated as 77 holdings. Based on the frequency distribution of herd size, the holdings were divided into three groups: 1-20, 21-45 and more than 46 head of cattle. The final sample was then proportionally distributed among these strata.

The stratified random sampling method used to determine the number of sample holdings was formulated as follows:

$$n = \frac{N\sum(N_h S_h^2)}{N^2 D^2 + \sum(N_h S_h^2)}$$

In this formula, n denotes the sample size, N denotes the total number of units in the population, Nh is the number of enterprises in the hth stratum, and Sh^2 is the variance of the hth stratum. The term $D^2 = (E/t)^2$ defines the allowable deviation from the population mean, where E is the permitted margin of error and t is the value corresponding to the selected confidence level.

In the study, the annual manure waste quantities of the enterprises were calculated, and their corresponding annual biogas production potentials (m^3. $year^{-1}$) were estimated. Accordingly, the assumptions and coefficients used in estimating the biogas production potential were as follows: the average live weight per head of cattle was taken as 450 kg; the amount of waste material produced per animal was 27 $kg.day^{-1}.animal^{-1}$; the dry matter content of manure was assumed to be 15 %; the recoverability rate of solid matter was 50 %; and the recoverable dry matter (DM) waste per animal was calculated as 2.025 $kg.day^{-1}$.

The annual biogas yield per head of cattle was accepted as 33 $m^3.year^{-1}$. From each cubic meter of biogas, 4.70 kWh of electrical energy could be generated, and the unit price of electricity used for domestic energy consumption was taken as USD 0.06 per kWh (United States dollar).

Statistical analysis

In the study, demographic characteristics of the farm operators, such as age, education level and farming experience, together with selected structural characteristics of the enterprises, were categorized and evaluated in relation to manure management responses. The relationships between manure management responses and these categorized variables were analyzed using Spearman rank correlation. Exact P values are reported in TABLE VI, and statistical significance was evaluated at the levels of $P < 0.05$ and $P < 0.01$. In cells where the expected frequency was below five, Fisher's exact test was used as a complementary procedure. All statistical analyses were performed using the SAS statistical software package (SAS, 2009).

Ethical approval for the research was obtained from the Social and Human Sciences Ethics Committee of Ondokuz Mayıs University (Decision No: 2016/152, 29 November 2016).

RESULTS AND DISCUSSION

Demographic and Structural Characteristics

The demographic characteristics of the participants from the 77 enterprises included in the study are summarised in TABLE I, while certain descriptive features of the enterprises themselves are presented in TABLE II.

TABLE I
DEMOGRAPHIC CHARACTERISTICS OF THE PARTICIPANTS IN THE STUDY

Characteristic	Frequency (fi)	Percentage (% fi)
Gender		
Male	73	94.81
Female	4	5.19
Age		
< 30	2	2.60
30 – 51	42	54.55
51 – 70	31	40.26
> 70	2	2.60
Education level		
Illiterate	1	1.30
Literate	4	5.19
Primary school dropout	5	6.49
Primary school	37	48.05
Secondary school	12	15.58
High school	14	18.18
Undergraduate / Postgraduate	4	5.19

The majority of the 77 farm owners who participated in the research were male (94.81 %), while female participants constituted only 5.19 %. In terms of age distribution, 54.55 % were between 30 and 51 years of age. In a study investigating the current status of dairy farming in Tekirdağ [13], it was reported that 33 % of the farm owners were between 36 and 46 years of age, 32 % between 46 and 56, 15 % between 26 and 36, 12 % between 56 and 76, and 7 % between 16 and 26 years. Research stemming from Konya places the average manager age at 45 [14]. By comparison, Wolf [15] focused on a US group of 65 heifer breeders and documented a mean age of 51 years.

Looking at education, the vast majority, or 81.81 %, completed primary and secondary levels, whereas university graduates comprised only 5.19 %. Such figures parallel educational profiles reported for farm managers elsewhere in Türkiye [13, 16, 17, 18]. Most owners also possess significant tenure, citing 16 years or more in dairy production. Yet, older age combined with limited schooling can impede the uptake of modern manure techniques. Previous work emphasizes that moving past entrenched habits requires strengthening producer expertise [19, 20, 21]. This validates our finding that traditional methods remain dominant.

TABLE II
SUMMARY INFORMATION ON FARM MANAGEMENT

Characteristic	Frequency (fi)	Percentage (% fi)
Farming experience (years)		
< 5	3	3.90
6 – 10	15	19.48
11 – 15	16	20.78
16 – 20	24	31.17
≥ 21	19	24.68
Type of production		
Fattening	1	1.30
Dairy	12	15.58
Mixed	64	83.12
Number of animals (head)		
1 – 20	19	26.39
21 – 45	35	48.61
> 46	18	25.00
Genotype distribution of animals		
Native	28 (9.07 ± 1.45)	18.54
Crossbred	51 (13.98 ± 2.18)	33.77
Culture breed	72 (42.59 ± 9.01)	47.68

Based on the structural analysis presented in TABLE II, a high proportion of enterprises (83.12 %) operated as mixed-type farms, engaging in both dairy and beef cattle production, whereas only 15.58 % focused exclusively on milk production. This predominance of mixed-type enterprises suggests a relatively low degree of production specialization, which may complicate housing, feeding, and manure management. If different animal categories are managed within the same infrastructure or under the same routine, category-specific requirements may be overlooked. Previous studies have shown that primiparous and multiparous dairy cattle differ in social, feeding, and lying behaviour, and that competitive group conditions can increase displacements and alter feeding and standing patterns, particularly in younger or lower-parity animals [22, 23, 24]. In addition, the nutrient content and agronomic value of manure vary according to animal type as well as feeding, water consumption, and storage and management conditions [25]. Therefore, in mixed-type enterprises, treating animals and manure as a single homogeneous unit may reduce management efficiency and limit the effective use of manure as an economic and environmental resource [22, 23, 24, 25].

Barn characteristics and animal welfare

The structural characteristics of the barns, including construction material, floor type, and bedding usage, are presented in TABLE III.

TABLE III
DISTRIBUTION OF SELECTED TECHNICAL CHARACTERISTICS OF BARNS WITHIN THE ENTERPRISES

Characteristic	Frequency (fi)	Percentage (% fi)
Barn location		
Detached	69	89.61
Under the house	2	2.60
Both types	6	7.79
Main construction material of the barn		
Stone	23	29.87
Mudbrick	1	1.30
Briquette	49	63.64
Brick	3	3.90
Mixed	2	2.60
Barn floor type		
Concrete	69	89.61
Soil	2	2.60
Wooden	1	1.30
Stone	1	1.30
Mixed	4	5.19
Type of bedding used		
Sawdust	4	5.19
Straw	30	38.96
Dried manure	–	–
Mixed	1	1.30
No bedding	42	54.55

In terms of the physical characteristics of the barns, it was determined that in most enterprises in Samsun province, the barns were constructed as detached buildings and that briquette was the main construction material. The barn floors were predominantly made of concrete, and 54.55 % of the enterprises reported not using any bedding material, while the remainder mainly used straw. The preference for hard flooring is functionally meaningful in relation to manure removal and hygiene; providing a slope of up to 4 % in concrete-floored barns facilitates the drainage of urine and manure into channels [26]. Similarly, Polat [27] reported that concrete is the most suitable material for barn floors. However, in enterprises where no bedding is used, animal welfare may be compromised. Hard, non-bedded lying surfaces may reduce lying time and increase the risk of hoof disorders and hock injuries in dairy cattle [28, 29, 30]. Barn hygiene and floor comfort directly influence health and welfare parameters in dairy cattle. For instance, Patoliya *et al*. [31] demonstrated that in farms where hygiene scores for barn floors were poor, the likelihood of lameness in cows was approximately ten times higher than in clean conditions. Therefore, the widespread absence of bedding in barns in Samsun indicates that current barn-floor and related manure management practices may require improvement from an animal welfare perspective.

Barn types and manure collection

The distribution of preferred barn types and manure collection practices is shown in TABLE IV.

TABLE IV
DISTRIBUTION OF PREFERRED BARN TYPES AND MANURE COLLECTION PRACTICES WITHIN THE ENTERPRISES

Characteristic	Frequency (fi)	Percentage (% fi)
Barn type		
Enclosed	45	58.44
Semi-open	30	38.96
Open	2	2.60
Manure collection method		
Tractor shovel	26	33.77
Scraper	8	10.39
Shovel and wheelbarrow	40	51.95
Manure scraper (mechanical)	3	3.90
Frequency of manure collection		
Once a month	21	27.27
Once every 3 months	14	18.18
Once every 6 months	5	6.49
Once a year	10	12.99
Other	27	35.07

In terms of barn types, it was determined that 58.44 % of the enterprises operated closed barns, followed by semi-open barns (38.96 %). This indicates that most dairy cattle in Samsun province are housed in fully enclosed structures isolated from outdoor conditions. Data from the Bursa region show that 78.8 % of dairy farms use closed-type barns [32]. In Tekirdağ, this share reaches 91 % [13]. Rates for semi-open barns vary by region, but closed barns remain the main choice across Türkiye. However, if ventilation is poor or manure is not removed regularly, these barns do not offer environmental benefits. Ammonia can build up and affect respiratory health, especially in winter when air exchange drops and NH3 levels increase [33, 34]. Exposure to ammonia above 4 ppm has been associated with lung lesions and clinical signs consistent with bovine respiratory disease [35, 36]. Regular manure removal and the use of dry bedding materials can reduce ammonia levels and support the improvement of health indicators by reducing the microbial load in barn air [37]. Furthermore, the NIOSH threshold limits of 25 ppm (TWA) and 35 ppm (ST) should be respected to protect worker health [38]. Accordingly, in closed shelter systems, routine manure removal and effective ventilation are critical.

Analysis of manure collection methods showed that most farms (51.95 %) remove manure manually with shovels and wheelbarrows, typically at irregular intervals. This result is in agreement with a study conducted in Van province: Bakır [39] reported that manure was removed manually using shovels, rakes and wheelbarrows in all dairy farms and none of the farms had a pit or lagoon system for manure accumulation or maturation. Similarly, in Edirne region, Önal and Özder [18] found that 94.7 % of the farms removed manure manually, 5.3 % used tractor shovels and none of them used mechanical or automatic scrapers. Overall, these results indicate that mechanization in manure management remains very limited, especially among small and medium-sized family farms in Türkiye.

Manure storage and utilization

The responses regarding manure storage methods and usage practices are presented in TABLE V and the statistical relationships between these practices and farm characteristics are reported in TABLE VI

TABLE V
DISTRIBUTION OF PREFERRED MANURE STORAGE AND UTILISATION PRACTICES WITHIN THE ENTERPRISES

Characteristic	Frequency (fi)	Percentage (% fi)
Manure storage method		
Sealed manure pit	7	9.09
Manure heap (yard storage area)	33	42.86
Spreading in open area	29	37.66
None	8	10.39
Manure utilization method		
For own agricultural use	66	85.71
Sale + own use	7	9.09
External sale only	2	2.60
Other	2	2.60
Is your manure management successful?		
Yes	28	36.36
No	33	42.86
No opinion	16	20.78

Regarding storage infrastructure, 42.86 % of respondents keep manure in open piles, and another 10.39 % lack any designated area whatsoever. Covered pits are uncommon and are reported in only 9.09 % of cases. Similar patterns have been reported in Kahramanmaraş [40] and Burdur [41], suggesting that suitable facilities are lacking in many areas. When infrastructure is weak, environmental risks increase, especially nutrient leaching into groundwater. In Tokat, direct discharge into riverbeds has also been reported [42]. These practices increase pollution and can raise greenhouse gas emissions. In many developed countries, this is addressed through strict rules, such as the EU Nitrates Directive [5] and the US Clean Water Act [6]. Türkiye updated its water protection rules in 2016 [43], but implementation remains limited.

From an economic perspective, 85.71% of farmers used manure as organic fertilizer on their own land. Similar patterns have been reported in studies from across Türkiye. For instance, in the Tokat region, 87% of enterprises applied manure on their own land, 5 % supplied it to neighboring farmers, 7 % sold it for income, and 1 % disposed of it into rivers as waste [42]. In the İzmir-Tire region, dairy farmers were reported not to engage in composting or processing to make manure more suitable for agricultural use, but instead to spread it directly onto fields [44]. In a study conducted in Denizli province, it was found that 60.6 % of the manure produced was used in the farm's own crop production activities, 15.2 % was partly used on-farm and partly sold, and 24.2 % was entirely sold due to the absence of farmland [45]. Similarly, in a farm in Mersin housing 57 head of cattle, 61.4 % of the manure was used on the enterprise's own land, 10.5 % was given to nearby farms, and 28.1 % was sold [46]. These data indicate that manure utilization practices in Samsun are consistent with nationwide trends in Türkiye.

Most producers, particularly in a period of rising chemical fertilizer prices, view barn manure as a valuable source of organic fertilizer and prefer to use it on their own land. This approach is positive in that it transforms manure from waste into an economic input. However, spreading fresh manure directly onto fields may lead to nitrogen losses. Proper composting techniques would allow matured farmyard manure to serve as a more efficient resource capable of reducing chemical fertilizer use [47].

When examining responses to the question “Do you consider your manure management to be successful?”, a statistically significant difference was found according to barn type: enterprises with semi-open barns evaluated their manure management as more successful than those with closed barns ($P = 0.024$). This may be attributed to the fact that manual cleaning of manure accumulated in closed barns is more labor-intensive, leading farm operators to perceive themselves as less successful. On the other hand, enterprises that regularly utilized manure on their own land were found to regard their manure management as more successful ($P < 0.05$). In other words, producers who stored and used manure systematically in agricultural activities tended to evaluate their management practices more positively and consciously.

TABLE VI
RELATIONSHIPS BETWEEN MANURE MANAGEMENT AND SELECTED CHARACTERISTICS OF THE ENTERPRISES

Characteristic	Yes	No	No Opinion	P Value
Age of farm operator				
≤ 30 years	1	1	0	–
30–51 years	15	19	8	0.1092
51–70 years	12	12	7	0.4464
≥ 71 years	0	1	1	–
Overall p-value	0.003	0.001	0.068	
Characteristic	**Yes**	**No**	**No Opinion**	**P Value**
Education level				
Below high school	3	6	1	0.046
High school and above	23	25	15	0.1730
Experience (years)				
< 5 years	2	1	–	0.563
6–10 years	6	9	–	0.438
11–15 years	3	8	5	0.305
16–20 years	13	5	6	0.093
≥ 21 years	4	10	5	0.195
Overall p-value	0.008	0.0894	0.9394	
Barn type				
Enclosed	15	18	13	0.765
Semi-open	13	15	3	0.024
Open	–	1	–	–
Overall p-value	0.705	0.001	0.012	
Manure utilisation method				
Own land	21	32	14	0.025
For sale	2	–	1	–
Not utilised	5	1	1	0.1017
Overall p-value	0.001	0.001	0.001	

*Exact P values obtained from Spearman rank correlation and Fisher’s exact test (where required because of low expected cell counts) are presented to allow flexible interpretation of significance levels.

Animal welfare and hygiene

According to the research findings, the fact that 85.71% of the farms apply manure directly to the land without any biological treatment and 10.39% lack any storage infrastructure creates a critical 'biosecurity gap' in terms of herd health and welfare. The uncontrolled management of fresh manure causes fecal-borne pathogens to persist cyclically on barn floors and in areas where forage crops are produced. In the literature, Van Horn *et al.* [26] emphasized that an effective manure management system is mandatory not only for environmental protection but also for pathogen control and herd hygiene. Indeed, a study by Patoliya *et al.* [31] determined that in farms where manure hygiene is not maintained and floor management is poor, the incidence of infectious lameness and health problems is ten times higher compared to hygienic conditions. As Donlon *et al.* [36] point out, the microbial burden and ammonia contact linked to ineffective manure handling suppress immune responses. This weakens resistance to bovine respiratory disease (BRD) and degrades general welfare. Viewed this way, practices in Samsun constitute a structural hazard explicitly threatening animal welfare, rather than just an agronomic flaw.

Biogas and energy potential

The estimated annual manure quantities and corresponding biogas-based electricity generation potentials for Samsun Province are presented in TABLE VII and TABLE VIII.

TABLE VII
ANNUAL MANURE QUANTITIES ESTIMATED FOR SAMSUN PROVINCE BASED ON THE POTENTIAL OF LARGE RUMINANT BREEDS[a]

Breed	Number of animals (10^3 head)	Estimated fresh manure quantity (10^3 tonnes.year^{-1})	Total solid matter production (10^3 tonnes.year^{-1})	Total recoverable dry matter waste (10^3 tonnes.year^{-1})
Native	75.5	744.7	111.7	55.8
Culture	106.0	1045.1	156.7	78.3
Crossbred	203.6	2,006.5	300.9	150.4
Total	**385.2**	**3,796.4**	**569.4**	**284.7**

[a]The assumptions applied in the calculations are as follows: average live weight 450 kg; fresh waste production of 27 kg.animal^{-1}.day^{-1}; dry matter content of cattle manure 15 %; dry matter production of 4.05 kg.animal^{-1}.day^{-1}; recoverability coefficient for solids 0.50; and total recoverable dry matter waste of 2.025 kg.animal^{-1}.day^{-1}.

The calculations made using the coefficients specified in the methodology show that the current cattle population in Samsun Province (≈ 385.20 × 10^3 head) produces approximately 3.80 million tons of fresh manure per year. This amount corresponds to 569.40 × 10^3 tons of total dry matter. After accounting for recoverability rates, the total recoverable dry matter available for potential processing was estimated to be 284.70 × 10^3 tonnes per year. These values underline the significant amount of biomass produced by the dairy sector in the region, which is largely underutilized.

Based on the waste potential in the TABLE VIII, the annual output is estimated at about 12.71 million m³ of biogas and about 59.75 GWh of electricity. This shows a large energy potential. At the national level, Türkiye's theoretical biogas potential is estimated at 4.8 billion m³ per year [48]. However, reaching this level faces technical and economic limits. High upfront costs and scale requirements make it hard for single farms to use this potential on their own. A more realistic option is producer cooperation and shared biogas plants. In Samsun, this approach could bring both economic and environmental benefits. Even if manure management accounts for only a small share (0.7 %) of global agricultural greenhouse gas emissions [3], further reductions are still needed to meet climate targets.

CONCLUSION

Evaluations of manure practices in Samsun Province show clear gaps, but also clear room for improvement. Many farms still rely on manual handling. Storage capacity and mechanized systems are often missing, which limits recovery of manure as a resource and increases environmental risk.

When managed well, manure is not only waste; it can also serve as a source of energy and an organic soil input. In the present sample, most farms reported using manure on their own land (85.71 %), but this use was generally based on direct field application rather than improved storage, composting, or energy recovery. Therefore, the main problem is not the complete non-use of manure, but its limited processing and low-value utilization, which reduces both environmental and economic gains. In countries with more developed livestock sectors, manure management has been progressively updated to increase the value recovered from this resource.

Türkiye needs a similar shift. This requires a policy package that connects several parts. First, welfare-related routines should improve through regular bedding use and routine manure removal. Second, technical sustainability depends on infrastructure such as biogas plants, sealed storage pits, and separation systems. Third, these measures require financial support, including grants and loans, so that farms can adopt them.

Progress also depends on producer awareness. These findings point to a practical barrier: farmers with limited formal education and strong attachment to traditional methods may resist new approaches. Extension services need to address this directly. These services should not only provide information but also show how to apply the methods and make the benefits of proper manure management visible.

Public demonstration projects by state agencies and producer associations can guide implementation. However, wider uptake will also depend on private investment. Market conditions should support commercial interest in biogas and manure processing. At the same time, regulation and monitoring should be stronger so that manure is managed without environmental harm.

For example, large farms could be required to build leak-proof manure pits, and penalties could be applied when regular barn cleaning is not performed. Overall, the Samsun findings suggest that efficiency, sustainability, and animal welfare can improve with targeted interventions. As more producers treat manure as a usable by-product rather than a waste, dairy farms in the region are likely to become more profitable, reduce environmental impacts, and improve welfare practices.

TABLE VIII
ESTIMATED ANNUAL BIOGAS AND ELECTRICAL ENERGY POTENTIAL DERIVED FROM CATTLE MANURE IN SAMSUN PROVINCE[a]

Breed	Number of animals (10^3 head)	Recoverable dry matter waste (10^3 tonnes.year^{-1})	Estimated biogas potential (10^3 m^3.year^{-1})	Electrical energy equivalent (MWh.year^{-1})	Annual electricity revenue (M USD.year^{-1})
Native	75.5	55.8	2,493.9	11,721.5	0.703
Culture	106.0	78.3	3,499.6	16,448.1	0.987
Crossbred	203.6	150.4	6,718.9	31,578.9	1.895
Total	**385.2**	**284.7**	**12,712.4**	**59,748.7**	**3.585**

[a]In this study, the annual biogas production per animal is assumed as 33 m³, the electricity generation potential of biogas is assumed as 4.70 kWh.m^{-3} and the unit price of residential electricity is assumed as 0.06 USD.kWh^{-1}.

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Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this article.

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