Chapter 7

Sustainability and Environmental Impacts in Dairy Cattle Farming in Türkiye

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Abstract

The dairy cattle sector in Türkiye is a strategically important component of animal production and therefore requires the establishment of sustainability in economic, social, and environmental dimensions. While the average lactation yield per cow in European Union countries is approximately 6.5 tons, this value in Türkiye has remained around 3 tons for many years. However, due to the increase in the number of purebred and crossbred cows over the last decade, the average milk yield has improved; in 2012, the yield was 2.5 tons/year, rising to around 3.2 tons/year in 2019. Although this trend is positive in terms of reducing the environmental load, it remains well below EU averages. The main constraints on the sector's sustainability performance are the small-scale farm structure, high feed costs, fluctuations in raw milk prices, lack of environmental infrastructure, and limited access to modern technology. The inability of small farms to invest in modernization, the rapid increase in feed prices compared to inflation, and the decline in the number of dairy cows threaten the economic sustainability of the sector. From an environmental perspective, manure management and pasture utilization remain significant problems, especially in small-scale farms. To achieve sustainability, it is essential to promote economies of scale through cooperatives and producer organizations, increase forage crop production, expand pasture rehabilitation programs, encourage the adoption of environmentally friendly technologies, and strengthen training and extension activities. Integrated policies in this regard will not only enhance producer welfare but also support the sector's long-term competitiveness.

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1. Introduction: The Importance of Dairy Cattle Farming in Türkiye

Dairy cattle farming holds strategic importance in Türkiye's agricultural sector and provides the rural economy with high-value-added food and employment opportunities. For many rural households, dairy production is the main source of income, and it contributes notably to the national economy (Turan et al., 2017). Türkiye ranks among the top ten countries in the world for annual raw milk production; for example, total milk output reached 22.96 million tons in 2019, and more than 90% of this was cow's milk (Semerci et al., 2020). In 2022, raw milk production was recorded at about 21.56 million tons (Demirel, 2025). The dairy sector is considered critical not only for nutrition, but also for rural development and food security. In Türkiye, dairy cattle farming is carried out largely by family farms, most of which are small-scale: in more than 75% of dairy farms, there are 1–6 milking cows (Bulut, 2025). While this structure highlights the sector's significant contribution to rural employment, it also presents certain challenges to productivity and competitiveness (Güven, 2024).

Dairy cattle production in Türkiye has grown significantly in recent years. According to official statistics, annual cow's milk production rose from 8.9 million tons in 2000 to 16.9 million tons in 2014, an 87.7% increase; during the same period, the total cattle inventory increased from 11.2 million to 14.1 million. This upward trend continued through the 2010s, and the number of milking cows steadily increased from the early 2010s to 2019. However, the sector faced fluctuations entering the 2020s. Especially in 2021–2022, rising input costs and market volatility led to many dairy cows being withdrawn from production and sent to slaughter, resulting in a decline in the dairy cattle population. The year-by-year change in cattle numbers is presented in Table 1 (TEPGE 2023; TUIK, 2024).

Table 1. Cattle numbers in Türkiye by year (TUİK, 2025)

Türkiye Cattle Inventory (Head)				
Years	**Cattle - Purebred**	**Cattle - Crossbred**	**Cattle - Native**	**Total**
1991	1.253.865	4.033.375	6.685.683	11.972.923
1995	1.702.000	4.776.000	5.311.000	11.789.000
2000	1.806.000	4.738.000	4.217.000	10.761.000
2005	2.354.957	4.537.998	3.633.485	10.526.440
2010	4.197.890	4.707.188	2.464.722	11.369.800
2015	6.385.343	5.733.803	1.874.925	13.994.071
2018	8.419.204	7.030.297	1.593.005	17.042.506
2019	8.559.855	7.554.625	1.573.659	17.688.139
2020	8.838.498	7.594.127	1.530.274	17.962.899
2021	8.824.784	7.641.100	1.384.659	17.850.543
2022	8.295.825	7.324.866	1.231.265	16.851.956
2023	8.070.159	7.303.667	1.047.430	16.421.256

The place of dairy cattle in Turkish agriculture matters not only for production volume but also for productivity and quality. However, there is still room for improvement in the sector's efficiency. For example, while the average lactation yield per cow in European Union countries is approximately 6.5 tons, in Türkiye it remained around 3 tons for many years (Demircan et al., 2006). Low yield raises the cost per unit of product, limits competitiveness, and increases environmental impact. In recent years, government policies have expanded beyond simply raising productivity to focus on the sector's sustainable development (Yılmaz and Ata, 2016). As a result of the support provided, both milk output and the number of dairy cows have increased significantly (Torgut et al., 2019).

Today, with growing production volume but productivity factors that still need improvement, Türkiye's dairy cattle sector requires a complete treatment of sustainability in all its dimensions. In this section, within the concept of sustainable agriculture, the environmental impacts of dairy cattle, the practices carried out in Türkiye, and strategies for the future will be evaluated.

2. The Concept of Sustainable Agriculture and Its Implications for Dairy Farming

Sustainable agriculture is an approach that aims to meet today's needs without harming the resources of future generations and while protecting

the natural balance. In general, sustainable agriculture focuses on producing sufficient, high-quality food at a reasonable cost while safeguarding soil, water, biodiversity, and the well being of farmers (Ülger et al., 2024). This approach seeks to develop farm systems that are economically viable in the long term, environmentally sustainable, and socially equitable. Sustainability is not a single method; it encompasses various practices, including organic farming, good agricultural practices, and regenerative agriculture (Çukur and Saner, 2005). The ultimate goal is to maintain agricultural productivity while minimizing environmental damage, enhancing the quality of life for those working in farming, and ensuring the sustainability of rural communities.

The dairy sector is a crucial area for applying the concept of sustainable agriculture. This is because dairy cattle farming have a strong impact on sustainability in both economic terms (as a source of rural income and jobs) and environmental terms (greenhouse gas emissions, water, and land use). Sustainable dairy farming aims to meet the growing demand for animal protein while reducing its environmental footprint and protecting animal welfare (Çukur and Saner, 2005; Şengül et al., 2022). In this context, sustainability in dairy cattle is addressed under three main pillars:

- **Environmental sustainability:** Minimizing the negative effects of milk production on soil, water, and air, and aligning with nature's cycles. For example, managing pastures to avoid overgrazing, properly storing and using manure wastes, and adopting methods that reduce greenhouse gas emissions fall under this pillar.
- Economic sustainability: Keeping farms profitable and financially stable in the long run. The sustainability of dairy farms depends first on profitability; this requires lowering costs, increasing productivity, and building a structure that can withstand market volatility (e.g., reducing feed costs, investing in productivity-enhancing technologies) (Latruffe et al., 2016).
- Social sustainability: Improving the quality of life of farmers and workers, raising levels of training and organization, and ensuring animal welfare. Sustainability in dairy also encompasses protecting the health and well-being of individuals working in the sector and preserving the social fabric of rural communities (Lebacq et al., 2013).

From a sustainability perspective, increasing productivity in dairy cattle is a key strategic goal. Having milking cows that yield more milk per animal means fewer animals are needed for the same amount of milk; this

brings economic benefits and lowers the environmental impact per animal. In Türkiye, state policies have recently shifted from purely yield-focused support to building a competitive and sustainable dairy sector (Yılmaz and Ata, 2016; Başer, 2021). In line with this goal, measures such as promoting modern barns and milking systems, utilizing high-quality breeding stock, and supporting the production of feed crops have gained prominence. The sustainable agriculture mindset encompasses not only improving traditional methods with more eco-friendly practices but also utilizing innovative technologies. For example, solar-powered irrigation systems, smart herd management devices, and automatic milking and cooling systems can improve resource efficiency and support long-term sustainability of production (Keskinkılıç, 2019; Kalkan, 2019; Van Heurck et al., 2020; Şengül, 2020).

In short, sustainable dairy farming is a forward-looking approach that tries to balance production with the environment. Its success is closely tied to proper management of environmental impacts and making the current production system more resilient.

3. Environmental Impacts of Dairy Cattle Farming

Dairy cattle activities have significant environmental impacts because of natural resource use and waste outputs. The main areas are greenhouse gas emissions (carbon footprint), water use, land use, and waste management.

3.1. Carbon footprint and greenhouse gas emissions: The environmental side of sustainability looks at the total effects of human activity on ecosystems and is grounded in the natural sciences (Arvidsson et al., 2020). For livestock farms, discussions on environmental sustainability focus on greenhouse gas emissions, water and energy use, and waste management. Recent estimates put global greenhouse gas emissions at about 49 Gt CO_2e, of which roughly 5.4 Gt CO_2e comes from agricultural activities. About 3.9 Gt CO_2e of this is from livestock and animal manures. In other words, around 11% of total global emissions stem from agricultural production, and 7.9% directly from livestock and manure-related processes (Rotz, 2020).

The main greenhouse gases from animal production are methane, nitrous oxide, and carbon dioxide. In the livestock sector, key sources of emissions are animal housing and manure storage areas. When manure is removed from the facility daily or at short intervals, greenhouse gas emissions stay quite low. In contrast, long-term manure storage leads to substantial emissions (Rotz et al., 2019). For this reason, manure management is a critical stage

of production, especially for cutting methane and nitrous oxide emissions (Galioto et al., 2017). Dairy farming can also harm aquatic ecosystems through nitrogen and phosphorus pollution caused by manure application to soil and by overgrazing (Arvidsson et al., 2020). These issues demonstrate that implementing better feeding strategies, utilizing feed additives, and enhancing manure management can help reduce the carbon footprint. In summary, the dairy sector's impact on climate change mainly comes from methane emissions, and lowering this impact is a key sustainability goal.

3.2. Water use and water footprint: Milk production is water-intensive. Beyond the drinking water cows need, large amounts of water are used for growing feed crops, cleaning barns, and processing milk. According to water footprint accounting, producing 1 liter of cow's milk uses about 1,020 liters of water (De Vries and De Boer, 2010). This notable figure covers all stages, including rainwater used in feed production (green water), irrigation water (blue water), and the water needed to dilute pollution (gray water). In Türkiye, dairy cattle farming puts a two-way pressure on water resources: on one side, feed crops (corn silage, alfalfa, etc.) require high agricultural irrigation; on the other, intensive farms consume a lot of water for drinking and cleaning. In arid regions, the growing need for feed production makes the sustainable use of groundwater and surface water especially critical. From a sustainability perspective, improving water-use efficiency (e.g., using drip irrigation for feed crops, implementing closed-loop water systems) and protecting water resources are crucial. Otherwise, rising drought risk with climate change may make it harder to secure the water needed for milk production. In this context, adopting better water management practices in dairy farming is essential for both maintaining production and protecting ecosystems (Chriki and Hocquette, 2020; Leroy et al., 2022).

3.3. Land Use and Ecological Footprint: Raising animals for meat, leather, wool, and milk requires using feed grown on croplands, fish feed produced in natural waters or on farms, and pasture areas set aside for grazing. Worldwide, there are about 3.5 billion hectares of natural and semi-natural rangelands. When calculating the rangeland footprint, the amount of animal feed available for use in a country is compared with the annual amount of feed needed for all animals that is obtained from rangelands (Kitzes et al., 2007).

Dairy cattle farming needs large land resources for feed production. Feeding a dairy cow depends mostly on quality forages and concentrates, and producing these feeds uses agricultural land. In Türkiye, a significant share of field-crop patterns is allocated to forage crops (e.g., corn, alfalfa,

vetch, sainfoin). In regions with intensive dairy activity (especially Marmara, Aegean, and Central Anatolia), pressure on pastures and croplands is increasing. Overuse and uncontrolled grazing can weaken plant cover, leading to soil erosion. On the other hand, monoculture and heavy inputs (irrigation, fertilization) in feed-crop production can affect ecological balance. To prevent overgrazing and improper land use, it is essential to implement pasture management plans and promote sustainable techniques in feed-crop farming, such as rotation and intercropping.

Because feed from croplands, such as grains, is used more widely instead of herbaceous plants from rangelands, Türkiye's rangeland footprint ratio is trending down. This reduces the impact of animal product consumption on rangelands, yet increases the cropland footprint (Dinç, 2015). Using high-yield feed varieties and preservation methods such as silage can also increase feed produced per unit of land. These steps make it possible to get the same output with less land and reduce the ecological footprint.

3.4. Waste Management and Pollution: The main waste from dairy farms is animal manure. On large farms, properly storing and utilizing the high volume of manure is critical to both preventing environmental pollution and enable recovery. However, studies show manure management is often insufficient. For example, in a study of 100 dairy farms in Kütahya province, only 20% had suitable manure storage structures, while 80% kept manure in open piles (Şahin et al., 2001). The same research reported that nearly half of the farms (47%) were located very close to water sources, creating a risk of water pollution through manure leakage (Peypazar and Kılıç, 2021).

Without proper infrastructure, stored manure can carry nitrates and phosphorus into groundwater via rainwater, causing water pollution. Uncontrolled manure accumulation also creates odor and fly problems and can harm quality of life in residential areas. Solutions include locating farms far enough from settlements and sensitive water bodies, as well as promoting the use of leak-proof manure storage facilities. Managing manure in ways that do not harm the environment is also an opportunity: manure can be used in biogas plants to produce renewable energy, or composted and used as organic fertilizer. This can reduce fossil-fuel use and lower the need for chemical fertilizers. In Türkiye, some large-scale farms and integrated companies have begun producing biogas from manure to meet their energy needs, providing an example of a circular economy. However, waste management remains a significant challenge for small family farms and is a priority issue for environmental sustainability (Atılgan et al., 2006).

In summary, the environmental impacts of dairy farming are multidimensional. Elements such as carbon footprint, water and land use, and waste management need integrated improvement. The success of sustainability practices in the sector depends on correctly managing and reducing these impacts.

4. Sustainability Practices in Türkiye and Current Situation Analysis

In recent years, both the public and private sectors in Türkiye have taken various steps on sustainability in the dairy cattle sector. In this section, we assess the current situation and discuss the good practices already in place, as well as the overall level of sustainability in the industry.

4.1. Legislation and supports: From an environmental sustainability standpoint, there are several legal regulations for livestock farms in Türkiye. Especially for large-scale farms, the Environmental Permit and License Regulation sets conditions such as manure storage and wastewater treatment. The Ministry of Agriculture and Forestry provides training and grant support through programs like "Environmentally Friendly Agriculture" and "Good Agricultural Practices." For example, within rural development supports, new barn projects above a certain capacity are required to include manure pits and storage facilities, and grants are provided for these. Through IPARD (EU Rural Development) funds, investments for modernizing dairy farms (milking parlors, cooling tanks, biogas units, etc.) have also been supported. Thanks to this, many farms have improved their infrastructure and installed systems that increase energy and water use efficiency. However, there is still room to improve full enforcement of the rules and to bring small-scale farms under the same umbrella (Can and Esengün, 2007).

4.2. Training and extension: Applying sustainable farming principles in the field depends critically on farmers' awareness and knowledge. Provincial agriculture directorates and chambers of agriculture occasionally organize trainings on eco-friendly practices in dairy farming. For instance, seminars and demonstrations have been held on composting animal wastes, using manure in biogas plants, pasture management techniques, and organic milk production. Through dairy producer unions and cooperatives, efforts are also made to help members access sustainable production techniques (Pezikoğlu, 2006). These training activities are particularly important for helping young farmers adapt to new technologies and transition from traditional practices to greener methods. Still, there is a need to scale such training nationwide and reach farms of all sizes. In particular, raising sustainability awareness

among small family farms will have positive long-term effects across the sector.

4.3. Good Examples and Pilot Projects: In Türkiye, several good practices have encouraged progress toward sustainable dairy farming. Some large integrated dairy companies (those that adopt a "farm to table" model) have built circular systems on their own farms. Firms like Sütaş, for example, convert crop residues and animal manure into energy in biogas plants and use that energy on their farms and in their factories; the solid fraction left after fermentation is returned to fields as organic fertilizer (Ata and Yılmaz, 2015). Such models serve as an example for waste recovery and reducing fossil-fuel use. Some large farms have also turned to renewable energy by generating their own electricity with solar panels and using solar power for irrigation wells.

In terms of water efficiency, some feed producers have transitioned from closed or sprinkler systems to drip irrigation. There have also been notable advances in animal welfare and productivity, including the introduction of automatic milking systems and cooling tanks, which have improved milk quality and reduced losses. Modern barns use ventilation and cooling (fans, misting/showering systems) to reduce heat stress (Sejian et al., 2018). In regions of Türkiye where summers are very hot, dairy farms report measures such as installing shade structures and using showering systems to lower heat stress (Dikmen and Hansen, 2009). By limiting productivity losses, these practices bring both economic and environmental gains.

4.4. Analysis of the Current Situation: Despite ongoing improvement efforts, the overall sustainability performance of dairy cattle farming in Türkiye has not yet reached the desired level. From an economic standpoint, rapidly rising feed costs and volatile raw milk prices in recent years have seriously constrained farm profitability. Along with steep feed prices, raw milk prices have often failed to keep up with inflation, putting many producers under pressure. As a result, a notable number of breeding cows were sent to slaughter, the milking herd shrank, and short-term milk output declined. This is a critical warning sign for the sector's sustainability.

On the environmental side, partial improvements have been achieved in large-scale farms, but problems persist among smaller ones. Many small farms still lack proper manure storage structures; manure is left in the open or spread randomly on land, keeping pollution risks for local water and soil ecosystems alive. Likewise, overgrazing and unplanned pasture use remain issues in some areas; therefore, pasture rehabilitation and management need to be adopted more widely.

There are however, positive trends, most notably in yield. With more purebred and crossbred dairy cows, the average milk yield per cow in Türkiye has risen steadily over the last decade. The average was about 2.5 tons per cow per year in 2012 and around 3.2 tons in 2019. In line with changes in herd size and yield, raw milk output fell in 2022 from 23.2 million tons in 2021 to 21.6 million tons in 2022, a 7.1% drop. Of total raw milk, 92.3% is cow's milk, 7.5% is sheep and goat milk, and 0.2% is buffalo milk (TEBGE, 2023). It appears that yields continued to rise into the 2020s. Farm-level evidence points in this direction even if official figures are not yet complete. Higher yield lets fewer animals produce the same volume of milk, which lowers the long-term environmental impact. Even so, average yields remain well below EU levels, so there is still ample room to improve.

In short, while awareness and effort around sustainable dairy are growing in Türkiye, structural and on the ground problems continue. On one side, integrated and modern farms operate with circular, eco-friendly methods; on the other, some small family farms still use traditional practices that are low-yield and relatively burdensome on the environment. This dual structure means sustainability policies and supports must both reach a broad base and be targeted by scale. The next section will discuss the challenges in this direction and propose solutions.

5. Challenges and Proposed Solutions

Türkiye's dairy sector faces a range of hurdles to becoming truly sustainable. These appear across economic, social, and environmental dimensions, and they interact with one another. Below are the main problem areas and practical ideas to address them:

5.1. Small scale and weak organization: A large share of dairy farms are very small (as few as 1–5 cows), which keeps them from benefiting from economies of scale. Smallholders struggle to build capital for modernization and to gain bargaining power. The result is lower productivity and, proportionally, a heavier environmental load (Uçum and Gülçubuk, 2018).

Suggested remedy: Encourage small producers to organize in cooperatives or producer unions. Shared milking parlors, cooling tanks, and manure processing units can be set up. Group purchasing can help lower input costs. In one district, for example, several small farms could jointly invest in a biogas or compost plant. Such an investment would be unrealistic for a single farm to make. Public support should also be redesigned so small farms can access it more easily (lower own-capital requirements, simpler applications and similar measures).

5.2. High feed costs and feeding challenges: Feed is the dominant cost in sustainable milk production. Producers in Türkiye are hit by rising prices for concentrate and forage. Weather variability can cut pasture productivity, and drought years reduce forage output. Buying feed from outside the farm, especially for smallholders, puts economic sustainability at risk (Alçiçek, 2021).

What might help: Widen the use of local feed resources. Promote on farm feed production, such as silage making and sowing forage crops. The state should continue to support strategic forage crops and distribute equipment that reduces post-harvest losses, such as silos and balers. Provide hands-on advice for ration optimization to raise efficiency. Identify region-specific least-cost rations and share them widely. Also invest in research and development on alternative feed sources, such as selected industrial byproducts and the smarter use of grazing, and deliver the results to farmers through extension.

5.3. Instability in milk prices: Sustainability depends on the producer selling milk at a profit. In recent years, price swings and periods when raw-milk prices lagged behind inflation have squeezed farmers, pushing many to cull animals (Ayyıldız et al., 2021). This creates a damaging loop: low prices shrink the herd, future supply tightens and volatility persists.

Policy options: Make sure the National Milk Council's reference price mechanism functions effectively. Update market prices regularly to reflect rising costs, and, when needed, use intervention purchases or skim milk powder supports to steady the market. A floor price or premium scheme that guarantees a reasonable margin would also keep producers in the sector and help maintain the national herd over time.

5.4. Compliance with environmental rules and gaps in enforcement: Türkiye imposes environmental duties on large farms, yet practice does not always match the rules. Small and mid-sized farms are often exempt from parts of the legislation or simply fall outside routine inspections. That leaves room for off standard practices in manure management and wastewater treatment.

Proposed fix: Pair tighter inspections with smart incentives to spread eco-friendly production. Raise the frequency of audits so that all farms above a given size meet minimum manure storage standards, while also creating voluntary compliance programs for smaller holdings. A label such as an **"Environment Friendly Farm Certificate"** could grant recognition and modest support to farms that meet defined criteria, building both awareness

and social pressure. Region-level manure solutions can also help: as seen in parts of Europe, manure collected across a district can be processed in a central biogas or compost facility. In this model, environmental investment happens at a regional scale, and smallholders can join the system (Ermetin and Bayramoğlu, 2010).

5.5. Climate change and adaptation issues: Rising temperatures, shifting rainfall, and extreme weather affect dairy directly. High heat and humidity in summer cause heat stress in cows, lowering milk yield and harming reproduction (Ermetin et al., 2023). Drought reduces forage output and pushes feed prices up. In short, climate change is a long-term test for dairy sustainability.

Suggested response: Put adaptation strategies to work at the farm level. Start with better housing: ensure adequate ventilation, fans, and sprinkler systems for cooling, along with sufficient shade. Studies show that proper shade and showering systems clearly reduce heat stress in dairy cows. Next, promote climate tolerant forages (e.g., drought tolerant corn varieties and alternative feeds) and expand their cultivation. With early-warning tools and meteorological guidance, farmers can prepare for extremes. For instance, ahead of a heatwave, increase access to water and, if needed, shift feeding to the cooler night hours. Over the long term, build climate resilience into breeding programs by supporting the use of heat tolerant local genotypes or crosses (Dağdemir, 2005).

5.6. Barriers to technology and finance: Many sustainability tools (biogas plants, solar panels, automatic milking and smart sensors) require sizable up front investment. For small and medium-sized farms, access to these technologies can be financially challenging, and limited technical expertise slows adoption (Özkan and Gürbüz, 2019; Özkan, 2023).

Ways forward: Offer farmer friendly finance models. Low-interest loans, leasing options, and grant schemes can make green technologies, such as biogas and solar, more attainable. Create long-term credit lines through state banks and the private sector to back these investments. On skills, provide hands-on guidance through provincial advisors and veterinarians. Young farmers adopt digital tools faster, so highlight successful cases with contests, prizes or demo farms. In selected regions, set up pilot sustainable farms that demonstrate integrated setups, such as sensor-based feed and milk yield optimization, energy from manure, and similar solutions to inspire and train others.

Taken together, these proposals form parts of a multi-layered approach to the sector's sustainability challenges. Improvements along the axes of organization, training, support, and oversight can help dairy move toward a model that is both environmentally and economically sound; however, local context still matters. Eastern Anatolia's small, pasture-based farms will prioritize different fixes than intensive operations in Marmara. Policies and projects should reflect these differences to utilize resources effectively and achieve meaningful impact.

6. Policy Recommendations and Forward-Looking Strategies

Strengthening sustainability in the dairy sector calls for broad, future-minded policies. Below are practical proposals and strategic directions tailored to Türkiye:

- **Develop an integrated sustainability strategy:** Within the Ministry of Agriculture and Forestry, prepare a "Sustainable Livestock Strategy Document" covering both dairy and beef. Define clear indicators, targets, and action plans for instance, five-year goals for GHG reductions, water savings, and the number of farms with organic/good-agriculture certification. Draft and monitor this strategy with all stakeholders (public bodies, universities, producer groups, private sector).
- **Use environmental incentives and taxation:** Encourage eco-friendly production with smart rewards. Offer extra milk premiums or tax relief to farms that send manure to biogas plants or use solar energy. Conversely, after a fair transition period, consider environmental taxes for large farms that fail to invest in required systems. As carbon markets grow, evaluate livestock carbon credits. Create a national mechanism that lets producers earn credits when they use methane reducing feed additives or carry out pasture improvement.
- **Boost innovation and R&D:** Fund university and institute projects that deliver durable fixes. Priority topics include methane-reducing feed additives, low-emission dairy genotypes, low-water-use forages, and converting manure into bioplastics/energy, with dedicated calls open via TÜBİTAK and TAGEM. Support start-ups with grants and incubators so made-in-Türkiye solutions can scale globally.
- **Embed sustainability in curricula:** Highlight sustainable livestock in agricultural high schools, veterinary schools, and faculties of agriculture. Ensure that new graduates are familiar with climate-smart

husbandry, lifecycle assessment, and water/carbon footprinting. Field staff who carry this mindset will guide farmers more effectively.

- **Advance animal-welfare and certification schemes:** Treat sustainability as a whole that includes welfare. Build a National Animal Welfare Certification for milk from herds with good housing, free movement areas, proper feeding, and veterinary care. Position certified products as a distinct market segment. With consumers placing more value on ethical, sustainable food, this both rewards producers and lifts the sector's image.
- **Roll out digital monitoring and early warning tools:** Create an integrated platform that combines meteorology and farm data to deliver real-time advice. Send alerts (SMS/app) before heat-stress events so farms can add shade/cooling and shift feeding to cooler hours. Track roughage stocks and prices; when shortages are anticipated, implement prompt policies (such as imports or alternative feed support). Encourage voluntary reporting of environmental metrics (manure output, energy use) from farms to inform data-driven policies.
- **Raise consumer awareness and steer the market:** Grow domestic demand for sustainable milk. Run campaigns that explain why eco-friendly production matters. Use labels like "ecological milk" or "carbon neutral milk" to open new channels. Let sustainable producers capture a modest price premium, encouraging others to follow suit. Encourage big retailers and processors to include sustainability criteria in supplier programs. In parallel with the EU Green Deal, prepare for tools such as carbon footprint labels or sustainability declarations in the food sector.
- **Pursue international cooperation and alignment:** As part of the global climate effort, set agriculture and livestock emission reduction pledges and a roadmap to meet them. As noted in the 2024–2030 Climate Change Action Plan, most farm sector emissions come from livestock and need targeted rules (Demir, 2025). Study effective policies abroad (e.g., methane charges in some countries, California's methane programs) and adapt them to Turkish conditions. Join FAO/World Bank initiatives in sustainable livestock to access technical and financial support.

These policies collectively form a long-term vision for a resilient dairy sector. The core idea is to balance incentives with obligations, include every

stakeholder in the process, and base decisions on sound evidence. The sector is dynamic, economic and environmental pressures shift—so strategies must stay flexible and be updated through regular monitoring and evaluation. Ultimately, real success hinges on a shared culture, where producers, consumers, and the public sector collaborate towards sustainability.

7. Conclusion

Dairy cattle farming in Türkiye are essential for nutrition and the economy, and it must be addressed from several angles under the lens of sustainability. This review shows that sustainability in dairy is not only an environmental matter but also an economic and social one. The introduction underlined the sector's national importance and noted that it relies largely on small family farms. Production has grown in recent years, yet some structural issues remain. Within sustainable agriculture, it is vital to keep resources intact while maintaining productive output, and to treat environment, economy, and society as a single framework.

Considering environmental impacts, there is clear room for improvement in carbon footprint, particularly in terms of methane, as well as water use, land pressure, and waste management. Cutting livestock emissions, handling manure and other wastes safely, using water efficiently, and protecting pasture ecosystems should be top priorities. Türkiye has already taken steps toward sustainability. Even so, the current picture reveals a dual structure. Large and modern farms have made partial gains, while many small holdings still face both economic strain and environmental risk. In recent years, rising costs led to the loss of breeding stock. That outcome shows the economic pillar is as critical as the environmental one.

Under the challenges section, key problem areas were set out with practical responses. The list includes small farm size, high feed costs, unstable milk prices, weak compliance with environmental rules, climate stress, and limited access to technology and finance. The common thread is the need for sector-wide transformation and capacity building. Cooperatives can unlock scale, lower input costs, and enable shared environmental investments. Smart public support can protect and guide producers. Training and extension can raise awareness and improve day-to-day practice.

At the policy level, broader measures can speed the shift. A national sustainability strategy for livestock, incentives and taxes aligned with environmental goals, R&D and innovation, stronger coverage of sustainability in education, and learning from international best practice can help the sector move faster. In the twenty-first century, when climate action

is a global necessity, dairy will need to aim for a smaller carbon and water footprint.

In summary, achieving sustainability in Turkish dairy farming requires a holistic approach involving multiple stakeholders. Farmers, public authorities, the private sector and consumers all have roles to play. Sustainable practices may bring initial costs and changes, yet they strengthen competitiveness and food security in the medium and long term. A more sustainable dairy sector means higher-yielding cows, a cleaner environment, more prosperous rural producers, and healthier generations. The following steps should not be postponed. National agricultural policy should give priority to dairy-specific sustainability programs so that Türkiye can align its deep livestock tradition with future needs and provide enough balanced food for today's citizens and tomorrow's.

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