Climate Hazard Assessment for Dairy Farming in Aydin, Türkiye: Preliminary Results from the CliResDairy Project

Çağrı Karaman[1], Hediye Cerit[2], Kemal Demirkol[1], Engin Koç[1], Elif İrem Köse Kiper[1], Göktuğ Yaşar Çukurlu[3], Nusret Demir[4,5*]

[1]GTE Karbon Sürdürülebilir Enerji Eğitim Dan. Tic. ve San. A.Ş
(cagrikaraman@faceteknoloji.com;kemal.demirkol,engin.koc,irem.kose@gte.com.tr)
[2]Aydın İli Damızlık Sığır Yetiştiricileri Birliği, Efeler, Aydın-Turkiye (hediyecerit@gmail.com)
[3]Akdeniz University, The Institute of Natural and Applied Sciences, Department of Space Science and Technologies 07258 Konyaaltı Antalya, Türkiye - 202351045003@ogr.akdeniz.edu.tr
[4]Akdeniz University, Faculty of Science, Department of Space Science and Technologies 07058 Konyaaltı Antalya, Türkiye - nusretdemir@akdeniz.edu.tr
[5]Eten R&D Ltd., Antalya Teknokent, 07070, Konyaaltı, Antalya, Türkiye

* Corresponding Author

Keywords: Dairy Farming, Climate Resilience, Hazard Assessment, Regional Climate Projections

Abstract

This paper presents the preliminary findings of a climate hazard assessment for the dairy farming sector in Aydin, Türkiye, conducted under the Climate Resilience Enhancement in Dairy Farming (CliResDairy) Project. Aydin is a vital agricultural province, ranking fourth nationally for its cultural breed cattle population and holding a significant position in regional milk production. However, the sustainability of the sector is increasingly threatened by impacts of climate change such as prolonged droughts and extreme temperatures. Using the standardized Climate Risk Assessment (CRA) framework of the European Union's CLIMAAX project, this study assesses four key hazards: heatwaves, agricultural drought, heavy rainfall, and river flooding.

The analysis, based on regional climate model projections, indicates that heatwaves pose the most severe and urgent threat, with their frequency projected to increase significantly in future climate scenarios, potentially reaching 6-8 events per year. Such events, where temperatures exceed critical thresholds for livestock health (32°C), directly reduce milk production and strain animal welfare. Currently, agricultural drought is projected to cause substantial yield losses for essential forage crops such as maize and wheat, leading to increased feed costs and threatening the financial viability of farms. Furthermore, an increase in the intensity of extreme precipitation and persistent risks of river flooding present additional threats to farm infrastructure, pastures, and general operations. These findings underscore the multi-faceted climate vulnerability of the Aydin dairy sector and highlight the urgent need for data-driven, targeted adaptation strategies to ensure its long-term resilience and sustainability.

Keywords: Dairy Farming, Climate Resilience, Hazard Assessment, Regional Climate Projections

1. Introduction

This paper outlines the preliminary results of a climate vulnerability and hazard analysis for the dairy industry in Aydin, Türkiye. This work is an integral part of the Climate Resilience Enhancement in Dairy Farming (CliResDairy) Project, which operates under the broader CLIMAAX framework. The primary objective of this project is to strengthen climate resilience in the dairy farming sector of the Aydın Province. Using the CLIMAAX Handbook, the project will conduct a multi-risk climate assessment to develop targeted adaptation strategies. The goal is to improve the sustainability of agricultural livelihoods, improve local adaptive capacities, and provide data-driven insights for policymakers. Ultimately, the project will promote sustainable resource management and climate-smart technologies to protect Ayd ı n's position as a sustainable agricultural hub against future climate risks.

Aydin province, located in the Turkish Aegean Region, is a major agricultural hub celebrated for its fertile lands and significant contribution to the national dairy sector. The province's economic importance is underscored by its high ranking in national livestock figures; Aydin ranks 4th among all provinces in Türkiye for its population of cultural breed cattle. The dairy industry in the region is predominantly characterized by small-scale operations, with approximately 17,000 dairy farming enterprises managing herds of 1-5 head. Within the Aegean region, Aydin holds the second position in total milk production, generating 566,298.09 tons annually, and ranks fourth for average milk yield per cow at 3,965 kg per year. These figures firmly establish Aydin's critical role in the agricultural economy of both the region and the nation (Sevim, 2022).

Despite its economic significance, the sustainability of Aydin's dairy sector is under considerable threat from accelerating climate change impacts. The region is increasingly vulnerable to hazards such as prolonged droughts, extreme temperatures, water scarcity, and unpredictable weather patterns. Rising global temperatures and shifting precipitation levels have already contributed to a notable increase in the frequency of heatwaves and extended dry spells. These environmental pressures are compounded by pre-existing challenges, including inefficient irrigation practices. Rising temperatures and reduced precipitation levels have contributed to an increase in the occurrence of heatwaves and dry spells (IPCC, 2022). Inefficient irrigation practices increase water scarcity and groundwater extraction (FAO, 2018). Despite efforts to promote modern technologies, financial and infrastructural barriers limit adoption, leaving dairy farming highly susceptible to prolonged drought (FAO, 2021).

The CliResDairy project aims to address these challenges directly. Its main objectives are to improve the sustainability of agricultural livelihoods by identifying and mitigating key climate risks; strengthen local capacities for adaptation through training and knowledge-sharing; provide data-driven insights to inform regional and national agricultural planning; promote

sustainable resource management; and encourage the adoption of climate-smart technologies. Using standardized methodologies, the project seeks to support evidence-based decision-making and improve collaboration among farmers, policymakers, and researchers to co-develop practical and effective adaptation solutions.

2. Materials and Methods

In the literature, studies use multi-member climate model ensembles and multiple milk loss estimation methods to produce gridded projections of heat-related milk loss and regional economic exposure (Fodor et al., 2018). This assessment was conducted within the framework of the EU-funded CLIMAAX project, which is designed to provide financial, analytical, and practical support to European regions to improve their climate risk management. A core component of the project is the development of a standardized Climate Risk Assessment (CRA) framework supported by a ready-to-use toolbox with data, models and utilities that access open data archives from Europe and the world.

The Climate Risk Assessment (CRA) for the Aydın Province focuses on evaluating the impacts of climate change, particularly on its key dairy farming sector. The assessment aims to identify high-risk areas and develop targeted adaptation strategies to increase resilience against threats such as drought and heat stress.

The CRA provides evidence-based insights to guide regional planning and help farmers adopt climate-smart practices. However, it faces limitations, including data gaps and resource constraints. Its success depends on strong stakeholder participation and the ability to overcome institutional barriers.

Despite these challenges, the CRA serves as a critical roadmap for climate risk management, supporting policies that ensure the long-term resilience of Aydın's agricultural sector.

This study applies dedicated workflows from the CLIMAAX framework to assess the specific hazards associated with heavy rainfall, agricultural drought, heatwaves, and river flooding in Aydin.

2.1 Study Area and Climate Profile

The study focuses on Aydin province, located in western Türkiye, which has a characteristic Mediterranean climate with hot, dry summers and mild, wet winters. According to ECMWF datasets (https://www.ecmwf.int/, the average annual temperature is approximately 17-18°C), with July being the hottest month (average high of 36.3°C) and January the coldest (average low of 8.2°C). Rainfall is concentrated in winter, with an average annual precipitation of 645.1 mm, making dry summers dependent on irrigation for agriculture. This climate profile makes the region particularly vulnerable to the selected climate hazards, which threaten agricultural productivity, water security, and livestock farming.

2.2 Hazard Selection and Assessment Methodology

The primary climate risks for the dairy sector in Aydin were identified through an initial screening process. These hazards were selected based on their direct and significant impacts on dairy operations.

• Heavy rains: Excess rainfall can cause barn flooding, damage to forage crops such as wheat and corn, and the proliferation of fungal diseases and parasites in humid conditions.
• Agricultural Drought: Decreased rainfall and depleted water resources reduce the production of forage crops, leading to higher feed prices and nutritional stress for livestock, which can affect fertility and productivity.
• Heat waves: Extreme heat causes significant stress in livestock, reduces feed intake, decreases milk production, and increases health problems. Temperatures above 32°C are known to reduce milk production, while prolonged exposure above 38°C severely affects cattle health.
• River Flooding: Flooding from the Büyük Menderes River can submerge pastures and cultivated lands, causing extensive damage to infrastructure and forage crops.

For the quantitative hazard assessment, the analysis utilized EURO-CORDEX (EUR-11) climate projections at a spatial resolution of 12 km. It is the European branch of the international Coordinated Regional Climate Downscaling Experiment (CORDEX), an initiative under the World Climate Research Program (WCRP). Its purpose is to produce improved high-resolution regional climate projections for Europe by taking coarse data from global climate models and downscaling them to a finer scale. The selected specific model chain was the KNMI-RACMO22E regional climate model (RCM) driven by the ICHEC-EC-EARTH general circulation model (GCM), chosen for its effectiveness in simulating Mediterranean climate variability and precipitation patterns. KNMI refers to the Royal Netherlands Meteorological Institute. This is the national center for weather and climate research in The Netherlands. RACMO is the regional atmospheric climate model. It is a research model developed by KNMI in cooperation with the Danish Meteorological Institute. So, the KNMI-RACMO22E is a specific version of the model. The search results mention versions like RACMO1, RACMO2, and RACMO2.1. While "22E" is not explicitly defined, it is a version number, likely used in a specific project like EURO-CORDEX. The analysis compared a historical baseline period (1976-2005) with future projections for the mid-century (2041-2070) under two Representative Concentration Pathway (RCP) scenarios: RCP 4.5 (intermediate emissions) and RCP 8.5 (high emissions).

3. Results

Hazard assessment reveals significant and increasing climate-related challenges for the Aydin region across the four selected hazards.

3.1 Extreme Precipitation

The analysis of extreme precipitation indicates a likely increase in the intensity of rainfall events, increasing the risk of both urban and agricultural flooding . Figure 1 illustrates the expected precipitation over a 24-hour period for a 100-year return event, comparing the historical baseline (1976-2005) with a projected future scenario (2041-2070). Projections show that the most significant increases in extreme rainfall are expected in the central and eastern regions of Aydin .

Further risk analysis established a critical threshold of 100 mm of rainfall in 24 hours for the region . Under the RCP 8.5 scenario, the return period for such an event is projected to decrease significantly, particularly in southern and coastal areas, where these extreme events could become more frequent, recurring every 5 to 10 years. Critically, many of Aydin's dairy farms are concentrated in areas projected to experience the highest increases in extreme rainfall, posing a direct risk to farm infrastructure, pasture conditions, and transportation networks, thereby threatening the sustainability of dairy operations

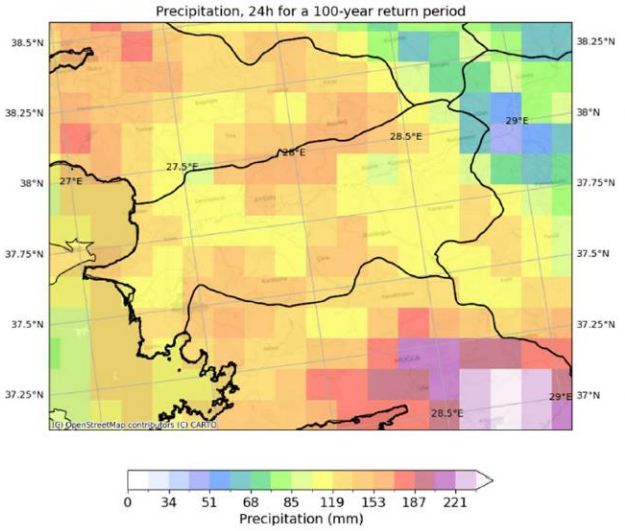

Figure 1. Map of Expected 24-Hour Precipitation for a 100-Year Return Period in the Aydin Region: Historical (1976-2005) and Future (2041-2070) Periods

Figure 1 shows The map visualization of the total amount of rainfall in millimeters (mm) over a 24-hour period. The data represents a 100-year return period event, which is a rare, high-magnitude climate event that has a 1% chance of occurring in any given year. Based on the context provided in the document and the comparison with the figure on the right, this map illustrates the historical baseline for these extreme events, specifically from the period 1976-2005.

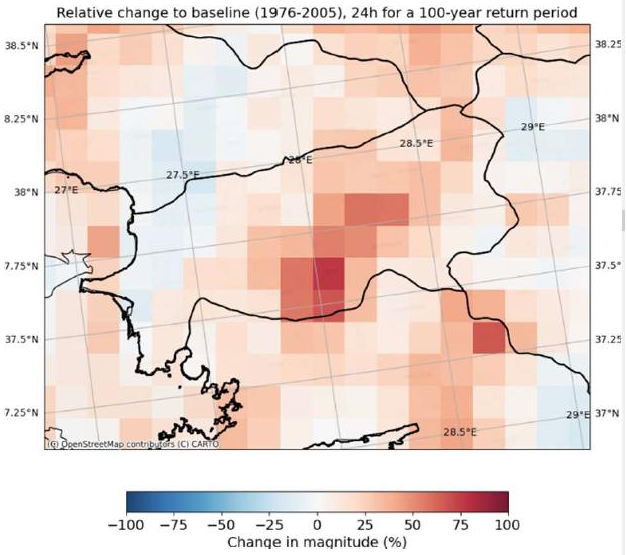

Figure 2. Projected Relative Change in 24-Hour Precipitation for a 100-Year Return Period in the Aydın Region (2041-2070 vs. 1976-2005)

Figure 2 shows the projected relative change in extreme precipitation events for the Aydın region. It compares future rainfall projections to a historical baseline to visualize how the severity of these events is expected to change. The map illustrates the percentage change in the expected amount of rainfall over a 24-hour period for a 100-year return period. A 100-year return period event is a climate event of such a magnitude that it has a 1% chance of occurring in any given year.

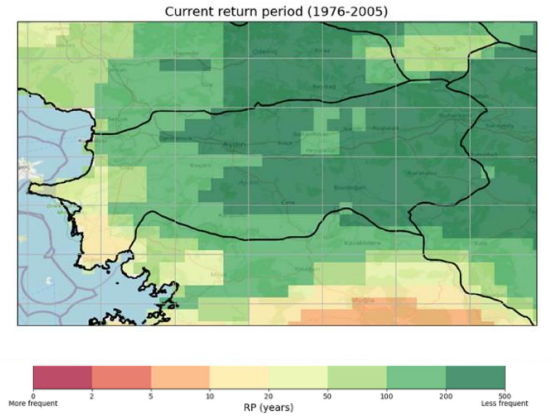

Figure 3.The return period

Figure 3 visualizes the return period (RP) in years for a rainfall event that exceeds a threshold of 100 mm in 24 hours. The return period is a statistical measure of the frequency with which an event of a given magnitude is expected to occur on average. A shorter return period indicates a more frequent event, while a longer one indicates a less frequent event.

3.2 Heatwaves

Heat stress drives direct physiological and behavioral disturbances in dairy cows and is the most frequently assessed hazard in the literature (Herbut et al., 2018). Heatstress stands out as a crucial and extensively researched climate threat to dairy systems. The Temperature-Humidity Index (THI) continues to be the main method of evaluation. It directly influences milk yield, reproductive success, and animal well-being. There is increasing concern in typically temperate areas due to climate change. Heatwaves are anticipated to become more frequent and intense, significantly endangering livestock health and productivity.. For this analysis, a heatwave was defined as a period of at least three consecutive days with a maximum temperature above 35°C and a minimum temperature above 20°C. Figure 4 shows that while heatwaves were historically rare, their frequency is projected to increase substantially. Under the RCP 8.5 scenario, Aydin could experience 6-8 heatwave events per year by the late century.

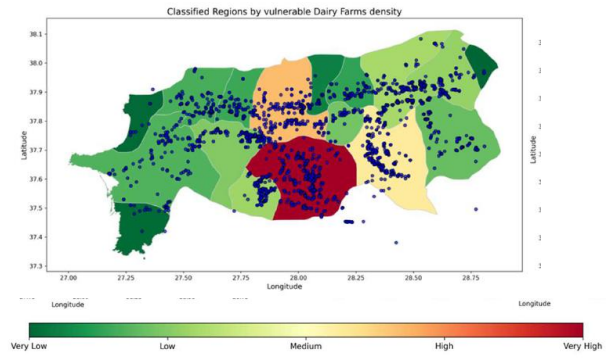

Figure 4. Dairy farms density classified by vulnaribility.

The risk assessment combined these hazard data with dairy farm density maps to identify areas of high vulnerability. The results indicate that the central and southeastern parts of Aydin face the most substantial increase in the risk of heatwaves. The high

concentration of dairy farms in these zones suggests that a large portion of the sector will be exposed to more frequent and intense heat stress, which is known to reduce milk production and negatively impact animal health.

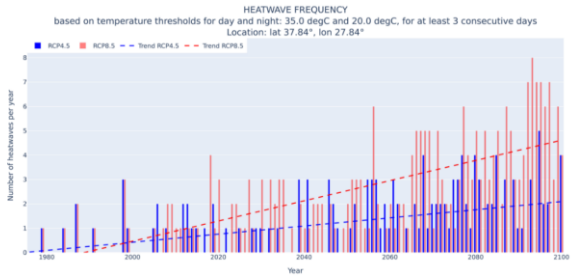

Figure 5. Heatwave Frequency in the Aydin Region under RCP 4.5 and RCP 8.5 Scenarios

Figure 5 shows the historical and projected frequency of heatwaves in the Aydın region from 1980 to 2100. Visualizes the number of heat waves per year in two different future climate scenarios. The y-axis represents the number of heatwaves that are expected to occur each year. A heatwave is defined as a period of at least three consecutive days where the maximum temperature is above 35°C and the minimum temperature is above 20°C. The x-axis covers a long period from the historical past (starting in 1980) to the end of the century (2100). The graph clearly shows a rising trend in heatwave frequency under both scenarios, with the high-emission RCP8.5 scenario showing a much more pronounced and dramatic increase, projecting a significantly higher number of heatwaves per year by the late twentieth century compared to the RCP4.5 scenario.

3.3 Agricultural Drought and Yield Loss

Agricultural drought presents a major risk to the production of essential forage crops such as maize, wheat, sorghum, and barley, which are crucial to the survival of the dairy industry . In the literature, drought and food scarcity are reported to reduce forage availability and increase feed costs, affecting smallholder and rainfed systems -, especially in East Africa (Nalianya et al.,2020)

Figure 5 illustrates the projected yield losses for maize and wheat between 2046 and 2050 under the high-emissions RCP 8.5 scenario. The analysis shows that some areas could experience yield losses exceeding 40%, particularly in the northeast for wheat and in the central and southern parts for maize.

The economic risk assessment translated these yield losses into potential revenue losses, or "lost opportunity costs"

. Projections indicate that revenue losses could exceed 400 USD per hectare for maize in the most affected areas, which are concentrated in the southwestern and central parts of the region. While wheat production appears slightly more resilient, the substantial financial strain on maize cultivation—a critical feed source—could have cascading negative effects on the local dairy industry's profitability and stability.

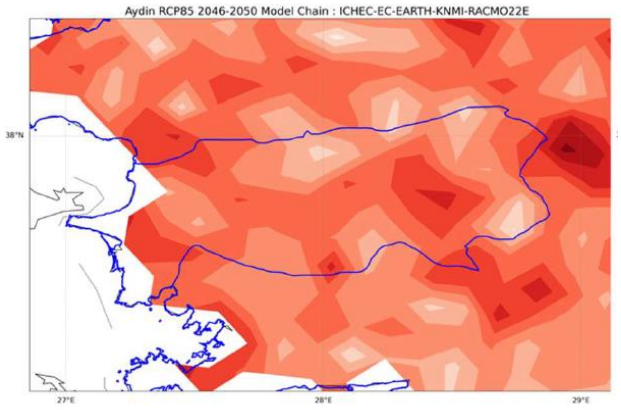

Figure 6. Yield Loss Due to Precipitation Deficit for Maize (Left) in the Aydin Region (2046-2050) under RCP 8.5 Scenario

3.4 River Flooding

In the literature, extreme weather events (heavy rainfall, floods, storms) are mentioned to increase acute mortality and damage infrastructure, and change pathogen/vector dynamics and biosecurity risks (Amamou et al., 2018).

The risk of river flooding, mainly from the Büyük Menderes River, remains a critical concern for agricultural lands in Aydin. Using high-resolution flood maps from the Joint Research Center (JRC), this assessment analyzed the flood potential for current climate conditions. Figure 4 displays the river flow potential across different return periods (1, 50, and 100 years). The analysis shows that flood-prone areas expand significantly from a 10-year to a 100-year event, with low-lying agricultural areas and the coastal delta region being particularly vulnerable to deeper inundation.

The risk assessment, which combined flood maps with land use data and vulnerability curves, confirms that farms located near the river and in low-lying plains require proactive flood adaptation measures to mitigate potential damage to infrastructure and pastures.

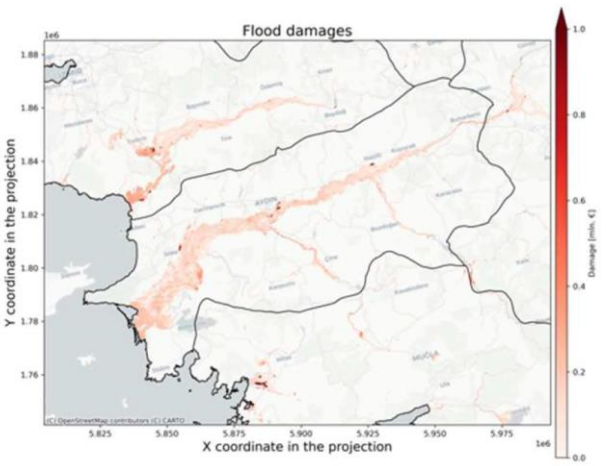

Figure 7. Flood damages

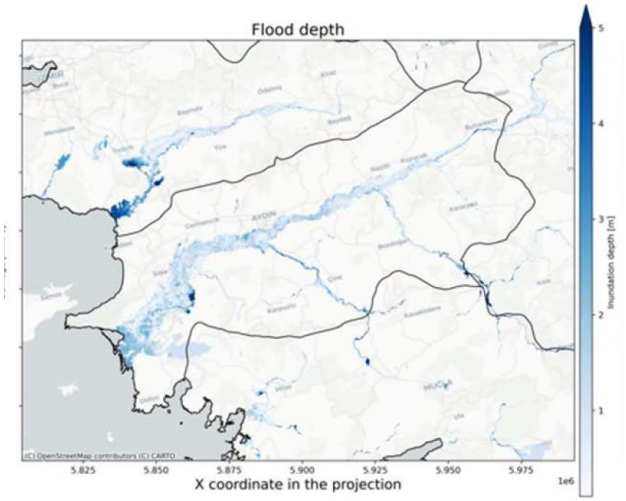

Figure 8. Flood depth

It is clear that Figures 7 and 8 have a high correlation.

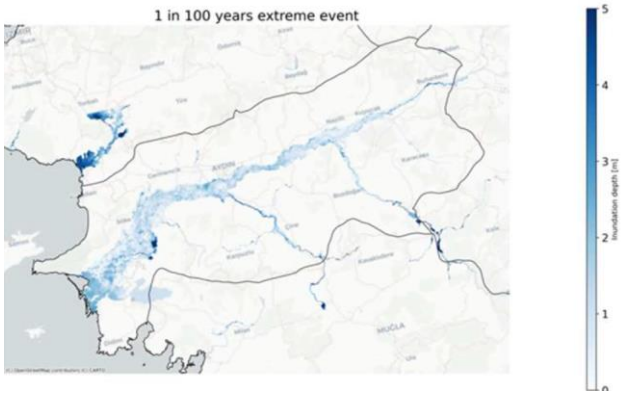

Figure 9. River Flow Potential for Different Return Periods 100 Years) in the Aydin Region

Figure 7-8-9 highlight that dairy farms near rivers and in low-lying areas need proactive flood adaptation and strategic planning to mitigate flood risks.

4. Discussion

Hazard and risk analysis indicates that Aydin is vulnerable to multiple, compounding climate hazards. Among these, heatwaves pose the greatest and most urgent threat to the region's dairy farms. Rising temperatures also directly contribute to increased drought, further stressing water resources and agricultural yields. A climate risk management framework exists in Aydin, built on collaboration among national and local institutions. However, stakeholder consultations revealed significant capacity gaps, including the need for improved water management, modernized irrigation, and expanded climate advisory services. Key challenges remain in data accessibility, financial constraints for technology adoption, and inter-institutional coordination. The use of spatially explicit climate ensembles such as EURO-CORDEX to project future hazards is a recommended approach to capture regional climate variability and uncertainty. Furthermore, the study's quantitative analysis of impacts, such as linking precipitation deficits to crop yield and subsequent revenue losses, aligns with the use of integrated farm system models to evaluate economic outcomes. The project's deep reliance on stakeholder engagement to identify risks and adaptation priorities also corresponds with participatory methods and vulnerability frameworks highlighted as essential for capturing local risk perception. The CliResDairy assessment confirms that temperatures exceeding 32°C are a critical threshold for milk production in Aydin, underpinning the urgency of the threat of heat waves. The economic analysis showing potential revenue losses exceeding 400 USD per hectare for maize due to drought mirrors the findings of other regions that report substantial economic losses. Importantly, the literature emphasizes the increased vulnerability of small farmers to food scarcity and constrained adaptation capacity. This is particularly relevant for Aydin, where the dairy sector is dominated by small-scale enterprises, making the project's focus on this demographic highly consistent with identified global research priorities. The adaptation needs identified for Aydin align with a portfolio of strategies recommended in the literature, which emphasizes combining short-term welfare measures with long-term systemic changes . The focus on improved cooling and microclimate management, enhanced feed and water security through drought-resistant crops and efficient irrigation, and the need for enabling policies and farmer training are all core strategies identified in the literature. In addition, the CliResDairy project directly addresses several key research gaps. By providing a high-resolution, localized risk assessment, it contributes to improved spatial characterization; by focusing on the needs of a smallholder-dominated region, it addresses the call for more research relevant to this group; and by aiming to develop policy briefs and training materials, it works toward operationalizing decision support tools for farmers and policy makers.

5. Conclusions

The preliminary results of the CliResDairy project present a clear hazard assessment for Aydin’s vital dairy sector, identifying the most pressing climate risks that threaten livestock health, milk production and the general sustainability of farms in the region. This assessment underscores that the sector is facing a multi-faceted threat from extreme heat, agricultural drought, heavy rainfall, and river flooding.

The findings indicate that increasing temperatures and an increased frequency of heat waves, particularly under higher emissions scenarios, will create stressful conditions for livestock, with temperatures exceeding 32°C being a critical threshold. Simultaneously, water scarcity and declining soil moisture levels are projected to intensify agricultural droughts. This will directly impact the viability of forage crops such as maize and wheat, limiting yields, increasing feed costs for farmers, and straining the financial stability of the entire dairy farming system.

Furthermore, projections for extreme weather events show that both heavy rainfall and associated river flooding pose significant threats. These hazards can cause direct damage to pastures, disrupt or destroy essential dairy infrastructure, and disrupt farm operations, thereby compounding the economic and operational risks faced by farmers in Aydin. In summary, this hazard assessment provides a foundational understanding of the climate-driven challenges ahead and highlights the urgent need for targeted adaptation and resilience strategies to protect the future of dairy farming in the region.

For the second phase of the project, stakeholder consultations have been conducted; key concerns raised included agricultural drought, extreme heat, and the need for improved water

management. The stakeholders emphasized the need for better crisis management in irrigation, stronger climate advisory services, and greater involvement of environmental and agricultural organizations. Key gaps in financial challenges for technology adoption, infrastructure modernization, and the integration of renewable energy were identified, highlighting the need for continued technical and financial support.

Acknowledgment

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