LEAKAGE ANALYSIS
OF THE LIVESTOCK SECTOR IN PANAMA

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1. Introduction

Carbon leakage poses one of the most significant threats to the environmental integrity of carbon offset projects. It occurs when emission reductions achieved within a project's boundaries are undermined by increased emissions elsewhere, typically because of the displacement of economic activities such as agriculture, logging, or livestock. In land-use and forestry projects (especially Afforestation, Reforestation, and Revegetation -ARR- interventions) leakage frequently arises when activities like cattle ranching or agriculture are reduced in one area but expand in another, potentially negating the climate benefits of restoration efforts (Murray et al., 2004; Gan & McCarl, 2007).

Globally, leakage rates in ARR projects vary widely depending on the scale, context, and land-use drivers. A meta-analysis by Meyfroidt and Lambin (2009) found that displacement rates in land-use interventions can range from 10% to over 70%, particularly when market-driven forces (such as demand for livestock products or agricultural commodities) are strong. Similarly, a review by Gibbs et al. (2007) emphasized that projects without adequate safeguards and monitoring frameworks are particularly vulnerable to indirect land-use change and leakage. These concerns have led voluntary carbon standards to require detailed leakage risk assessments, including quantitative estimates and mitigation measures.

In Latin America extensive cattle ranching remains a primary driver of deforestation and land degradation; and as such, the risk of leakage in forest restoration projects is especially relevant (FAO, 2021). For example, in the Brazilian Amazon, studies have documented cases where forest conservation in one area has led to the relocation of cattle herds to frontier zones, increasing deforestation pressures elsewhere (Arima et al., 2011).

In Panama, similar challenges arise despite the country's relatively small size. Extensive cattle production plays a central role in land use, raising the risk that forest restoration efforts could inadvertently trigger displacement of ranching activities. For this reason, it is critical to analyze whether ARR initiatives have limited to no risk of causing deforestation of intact forests.

This document focuses on the case of the ARC Restaura Azuero project, developed by PONTERRA, which seeks to restore approximately 10,000 hectares of degraded lands in the Azuero Peninsula through ARR activities. The initiative works directly with cattle ranchers to transition land away from livestock production and toward ecosystem restoration. While this approach offers significant environmental benefits, it is crucial to highlight that such benefits are embedded in a context where leakage risks are inherently low. This is largely explained by structural features of the livestock sector and by the characteristics of the participating ranchers, both of which contribute to reducing the likelihood of displacement.

Building on this premise, the present analysis develops an economic assessment of Panama's livestock sector, with a qualitative emphasis on the Azuero region, to substantiate the argument that leakage risks under the ARR framework are limited. To reinforce this point, an econometric analysis was conducted using historical data on livestock and pasture expansion. In addition, it integrates qualitative evidence drawn from landholders participating in the ARC Restaura Azuero project, offering preliminary insights into potential leakage dynamics. Ultimately, the study aims to reinforce the credibility of ARC Restaura Azuero and to provide guidance for the design and implementation of other nature-based climate solutions in Panama and beyond.

The document is structured in 5 sections: Section 2 presents the methodology, encompassing three complementary components. First, a descriptive analysis of Panama's livestock sector examines trends in production, consumption, and incentives (such as prices) to provide contextual understanding. Second, an econometric analysis using time-series data on herd size and pasture area estimates the relationship between livestock growth and pasture expansion, offering quantitative insights into potential leakage risks. Third, a qualitative component details the procedures for data collection with landholders participating in the ARC Restaura Azuero project, providing field-based perspectives on leakage dynamics. Section 3 integrates the findings from the descriptive and econometric analyses to develop hypotheses about possible leakage, while Section 4 presents results from the qualitative analysis. Section 5 summarizes the main findings and offers practical recommendations to strengthen the effectiveness and credibility of ARR initiatives.

2. Methodology

The methodology used comprises 3 components: analysis of market trends mainly based on national secondary data; the estimation of an econometric model to support the results from the market trend evaluation; and a qualitative analysis based on a survey applied to ranchers participating in the project. The approaches to each component are presented in this section.

2.1. Analysis of Panama's livestock sector

The analysis of Panama's livestock sector was conducted using secondary statistical information mainly from national sources and complemented with international data when needed. The methodological strategy combined a descriptive and comparative assessment of historical trends with the construction of indicators to examine dynamics in production, consumption, trade, and land use related to livestock.

The data was collected from:

- Agricultural Censuses of Panama (2000 and 2011): provided provincial-level data on pasture area, number of ranches, livestock heard size, and agricultural land distribution.[1]
- Food and Agriculture Organization of the United Nations (FAOSTAT, 1961–2022): the primary source for national time series on meat and milk production, per capita

[1] Data from the 2024 census was not used as it was not made available while preparing the report.

consumption, prices, trade balances and Greenhouse Gas (GHG) Inventories (methane (CH_4) and nitrous oxide (N_2O)

- National Institute of Statistics and Census (INEC): complementary information on land use, rural population, and sectoral economic activity.

Annual time series on production, consumption, prices, and trade were standardized into comparable units, including tons, liters, kilograms per capita, and hectares. This process ensured consistency across variables and facilitated intertemporal analysis. Census data from 2000 and 2011 were organized into a provincial panel, allowing for the construction of relative indicators such as the proportion of farms without livestock, stocking rates (hectares per animal), and the share of pastures within total agricultural land. In addition, emissions data were harmonized and expressed in gigagrams of CO_2 equivalent, which enabled coherent and consistent temporal comparisons across the study period.

A descriptive trend analysis was undertaken to examine the evolution of pasture area, herd size, production, consumption, and trade flows. Inter-census comparisons between 2000 and 2011 were employed to identify structural changes in land use and shifts in livestock efficiency at the provincial level. Furthermore, production pressure indicators were estimated to assess the relationship between changes in pasture area and drivers such as meat and milk prices, domestic consumption, and import dynamics. Finally, the trajectory of livestock-related greenhouse gas emissions was contrasted with production and consumption trends to evaluate consistency with processes of intensification or de-intensification.

2.2. Econometric analysis

The analysis was conducted using annual data, covering the period 1992–2021 in some cases and 1997–2021 in others, depending on data availability and model specifications. The main objective was to model the relationship between the growth of pasture area (the dependent variable) and a set of explanatory variables linked to livestock dynamics, trade, and relative prices. In the initial stage, a wide set of potential determinants was considered, including beef and chicken prices, the number of cattle heads, imports and exports of beef (both in quantity and value), and the implementation of the Free Trade Agreement (FTA) with the United States. However, due to the limited number of available observations (25, 26 or 30 years), model specifications were restricted to a maximum of two and four independent variables to avoid overparameterization and ensure the robustness of the estimates.

The dataset (Annex 3) was structured in a pure time-series format, with year as the time variable. All variables of interest were transformed into natural logarithms to allow interpretation of the coefficients as approximate elasticities. First-order differences ($\Delta \ln$) were generated to capture percentage changes, and when necessary, second-order differences were calculated to achieve stationarity. A dummy variable (*d_tlc*) was constructed to represent the implementation of the FTA (0 = no, 1 = yes).

Unit root tests were performed using the Augmented Dickey–Fuller (ADF) procedure. The results indicated that:

- *ln_price_meat* and *ln_meat_cattle_exports_quantity* were stationary in levels.
- *ln_pastures_area*, *ln_price_chicken*, *fta*, *ln_meat_cattle_imports_quantity*, *ln_meat_cattle_imports_value*, and *ln_meat_cattle_exports_value* became stationary in first differences.
- *ln_number_heads* and *ln_meat_price_index* required second-order differencing.

Based on these results, the working dataset combined first and second differences of the relevant variables, and cointegration analysis was discarded given the heterogeneous order of integration across series (Table 1).

Table 1. Variables included in the econometric models

Variable	Description	Units	Source	Transformation used in the model
Pastures area	Area of pastures	Hectares	FAO	First difference of log (dln)
Number of heads	Number of cattle heads	Heads	FAO	Second difference of log (d2ln)
Price meat	Producer price of beef	USD/ton	FAO	Log (ln)
Price chicken	Producer price of chicken (fresh or chilled)	USD/ton	FAO	First difference of log (dln)
Meat price index	Meat price index (aggregate)	Index (2014–2016=100)	FAO	Second difference of log (d2ln)
Meat cattle imports quantity	Beef imports – quantity	Tons	FAO	First difference of log (dln)
Meat cattle imports value	Beef imports – value	USD	FAO	First difference of log (dln)
Meat cattle exports quantity	Beef exports – quantity	Tons	FAO	Log (ln)
Meat cattle exports value	Beef exports – value	USD	FAO	First difference of log (dln)
FTA	Implementation of the Free Trade Agreement (FTA)	Dummy (0 = no, 1 = yes)	FAO / National sources	First difference (D)

Given these properties, an ARIMAX (AutoRegressive Integrated Moving Average with Exogenous Regressors) model was specified, where the dependent variable was the first difference of the logarithm of pasture area (*dln_pastures_area*). Six alternative specifications were estimated, combining different subsets of explanatory variables and ARMA structures:

- Model 1: ARIMA(1,0,1) with *d2ln_number_heads*, *ln_price_meat*, *dln_price_chicken*, and *d_fta*.
- Model 2: ARIMA(1,0,0) with *d2ln_number_heads*, *d2ln_meat_price_index*, *dln_price_chicken*, and *d_fta*.
- Model 3: ARIMA(0,0,1) with *d2ln_number_heads* and *dln_meat_cattle_imports_quantity*.
- Model 4: ARIMA(1,0,1) with *d2ln_number_heads* and *dln_meat_cattle_imports_value*.
- Model 5: ARIMA(1,0,1) with *d2ln_number_heads* and *ln_meat_cattle_exports_quantity*.
- Model 6: ARIMA(1,0,0) with *d2ln_number_heads* and *dln_meat_cattle_exports_value*.

The choice among specifications was guided by information criteria (AIC and BIC) as well as statistical significance of coefficients.

Residual diagnostics were performed to ensure the models satisfied the white noise assumption. The autocorrelation and partial autocorrelation functions of the residuals were inspected, and Ljung–Box Q-tests were used to confirm the absence of serial correlation.

2.3. Qualitative insights from ARC Restaura Azuero landholders

Primary data was gathered through a structured survey conducted with landholders involved in the ARC Restaura Azuero project in Panama. The survey was designed by Conservation Strategy Fund (CSF), validated by PONTERRA, and implemented by PONTERRA, between March and May 2025 (Annex 1).

Data collection was carried out through face-to-face interviews using a standardized introduction script that explained the objectives of the study, emphasized the confidentiality of responses, and clarified the voluntary nature of participation. Each interview lasted approximately 45 minutes on average.

The survey was designed following the guidance of the VERRA Leakage Mitigation Framework—specifically, Module VMD0054: *Estimation of Leakage from ARR Activities*—in order to rely on a standardized and credible reference for data collection in ARR projects. Accordingly, it included quantitative questions on land use changes before and after the ARR intervention (e.g., percentage of farm area allocated to forest, pasture, crops, or housing), livestock production data from 2020 to 2025 for both project and leakage mitigation areas (e.g., number of cattle raised, share sold vs. self-consumed, productivity per hectare), and management practices (e.g., type of cattle operation: breeding, fattening, or dairy).

In addition to the core variables required for VERRA methodology, the survey included qualitative questions to better understand the social and economic dynamics influencing participating households. These questions explored topics such as alternative income-generating activities and long-term motivations for participating in the ARR project. The full data collection is provided in Annex 2.

In total, 32 interviews were conducted. Five respondents were excluded from the analysis due to factors that prevented the estimation of key variables required for the application of the VERRA methodology, such as lack of historical land use data, absence of cattle ownership, or unavailability of information regarding mitigation actions. As a result, the final sample includes 27 valid surveys.

3. Results

3.1. Panama’s livestock sector

Panama's livestock sector is crucial in the country's agricultural landscape, contributing significantly to the economy and rural livelihoods. The industry includes various types of livestock production, such as cattle, pigs, poultry, and dairy farming.

Cattle farming is one of the most critical components of Panama's livestock sector. It includes both beef and dairy production. The country has a diverse range of cattle breeds adapted to different climatic conditions and production systems; beef production primarily focuses on the domestic market, but there are also export opportunities.

Dairy farming is concentrated in regions with favorable climatic conditions for milk production, such as Chiriquí and Veraguas. This sector faces challenges such as fluctuating milk prices and competition from imported dairy products. Efforts are being made to improve productivity and milk quality through better breeding practices and farm management.

Poultry farming significantly contributes to Panama's meat production, with chicken being a staple protein source for the population. Pig farming is also essential, with pork being widely consumed in the country. Modern production systems characterize both sectors and are relatively well-developed compared to other livestock industries.

The livestock sector in Panama faces several challenges, including disease management, climate change impacts, and competition from imported products. The Ministry of Agricultural Development (MIDA) in Panama implements policies to support the livestock sector, focusing on competitiveness, sustainability, and food security. Programs are in place to provide technical assistance, improve infrastructure, and help market access for livestock producers.

It is worth mentioning that Panama`s agricultural sector (agriculture, livestock, and fisheries) is relatively small, especially when compared with other Latin American and Caribbean (LAC) countries that are also highly dependent on tourism. The World Bank reports that agricultural production represented 2.8% of total production (GDP) between 2010 and 2019, below the LAC average of 4.7% (Egas Yerovi et al., 2023).

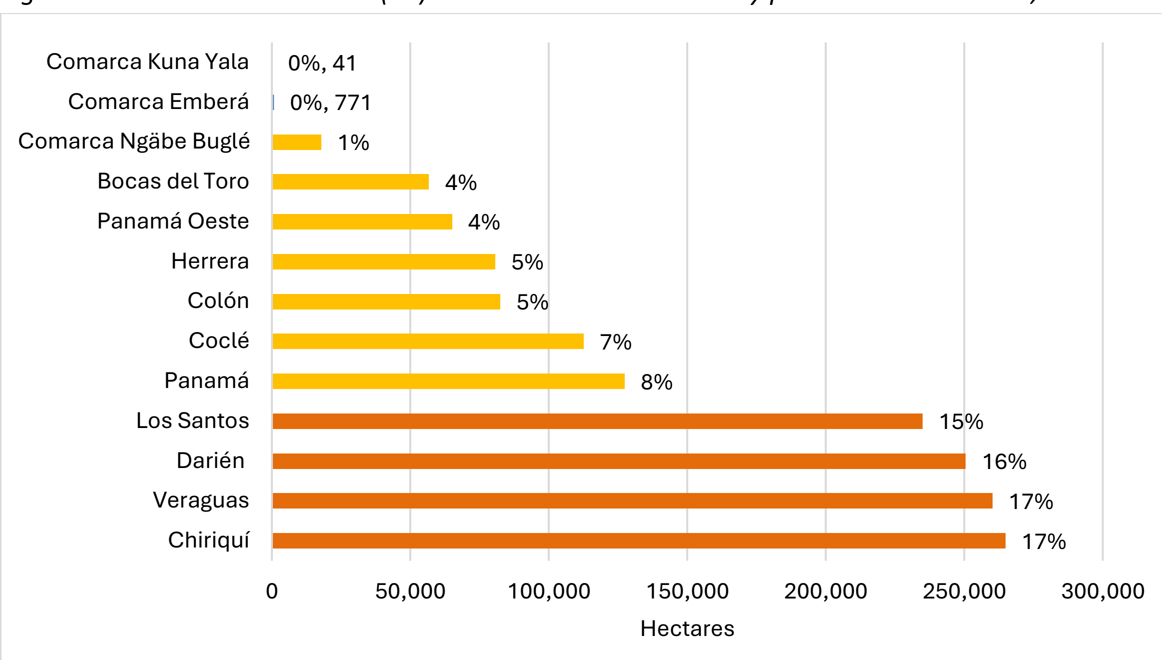
While agriculture`s contribution to the Panamanian economy is small, its significance cannot be overlooked at the subnational level. According to INEC data from 2019, the agricultural sector comprised over a third of the GDP in the province of Darién (33.9%), 18.6% in Los Santos, and 15.5% in Bocas del Toro. This demonstrates the vital role agriculture plays in the livelihoods of these provinces (Egas Yerovi et al., 2023).

This section draws primarily on secondary sources, including official statistics from FAO and INEC, as well as sectoral literature, and is complemented by survey data previously collected by Ponterra. Given the ongoing re-contracting process with landowners, no new surveys were conducted at this stage. Nevertheless, the available evidence, particularly the high share of underutilized pastureland, is sufficient to demonstrate that additional deforestation pressure is economically unlikely.

3.1.1. Production area

The latest census data from 2011 indicates that pastures covered a total area of 1,553,210 hectares (ha) in Panama. Pastures in Chiriquí, Veraguas, Darién, and Los Santos represent 65% of the national area dedicated to this activity. The other 35% is distributed between the provinces of Panama, Coclé, Colón, Herrera, West Panama, Bocas del Toro, and the Ngäbe Buglé Comarca. 771 ha and 41 ha are dedicated to pastures in the Comarca Emberá and the Comarca Kuna Yala, respectively (Figure 1).

Figure 1. Panama: Pasture area (ha) and share into total area by province and comarca, 2011[2]

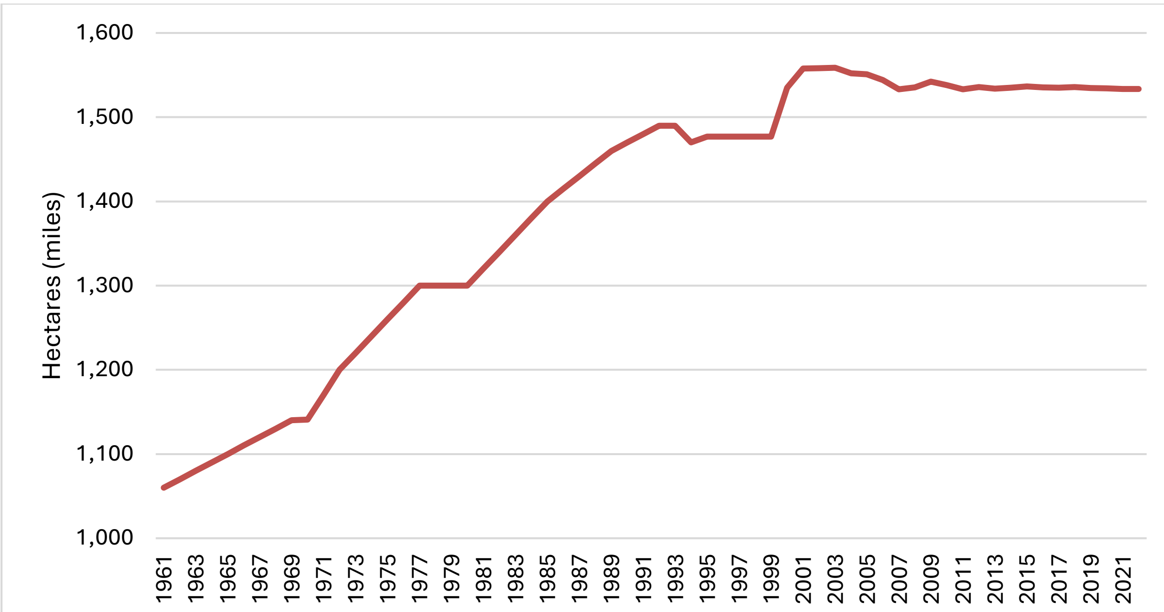


Note: data after their share for Comarca Emberá and Comarca Kuna Yala indicate the pasture area.
Source: Own from 2011 census data.

[2] The pasture area reported in the 2011 census was 1% higher than the reported on FAOSTATS. Because of the slight observed difference, it was decided that FAO data is good enough to be used for the historic trend analysis.

Data from FAO Stats (FAO, n.d.) was used to analyze the historical trend of Panama`s pasture area. From 1961 to 1999, the area dedicated to pasture increased at an annual average of 0.88%, going from an initial area of 1,060,000 ha to 1,535,000 ha. After 2000, the livestock sector continued expanding but at a slower pace. The average annual growth rate decreased to 0.17%, allowing the total pasture area to reach 1,534,000 ha in 2022 (Figure 2).

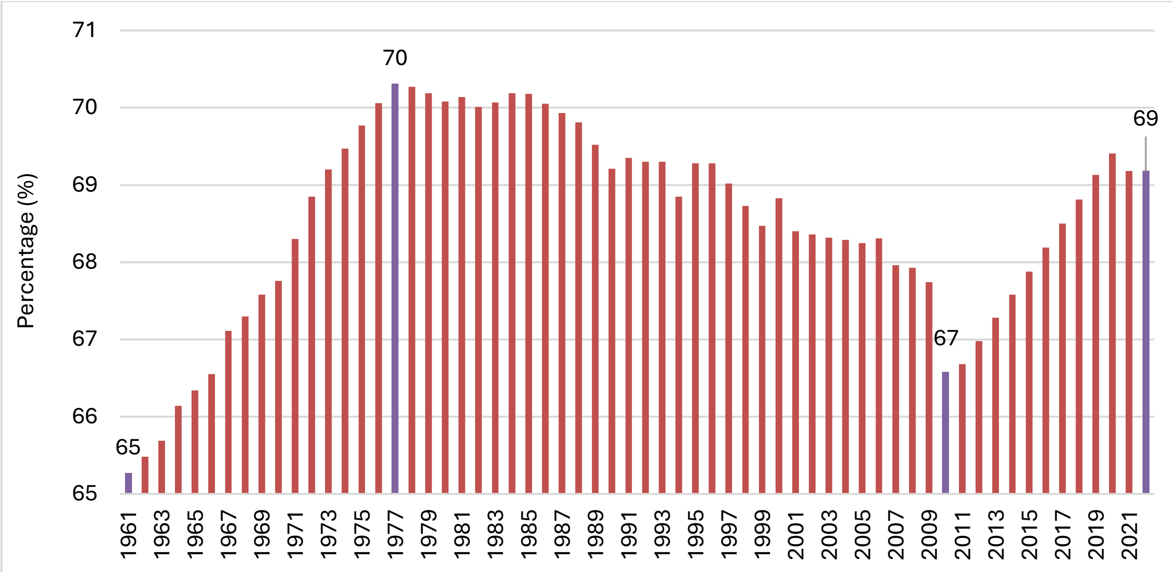
Figure 2. Panama: Total pasture area (1000 ha) from 1961 to 2022



Source: Own from FAO Stats data.

Interestingly, the share of pasture area in total agricultural land has oscillated between 65% and 70% from 1961 to 2020. It reached its maximum level in 1977, a year that started a decreasing trend until 2010, when this indicator reached a minimum of around 66%. After this period, the share of pasture area in agricultural land started growing again, up to 69% in 2022 (Figure 3). Currently, pastureland covers 20% of Panama`s total land area.

Figure 3. Panama: Share (%) of pasture area in agricultural land

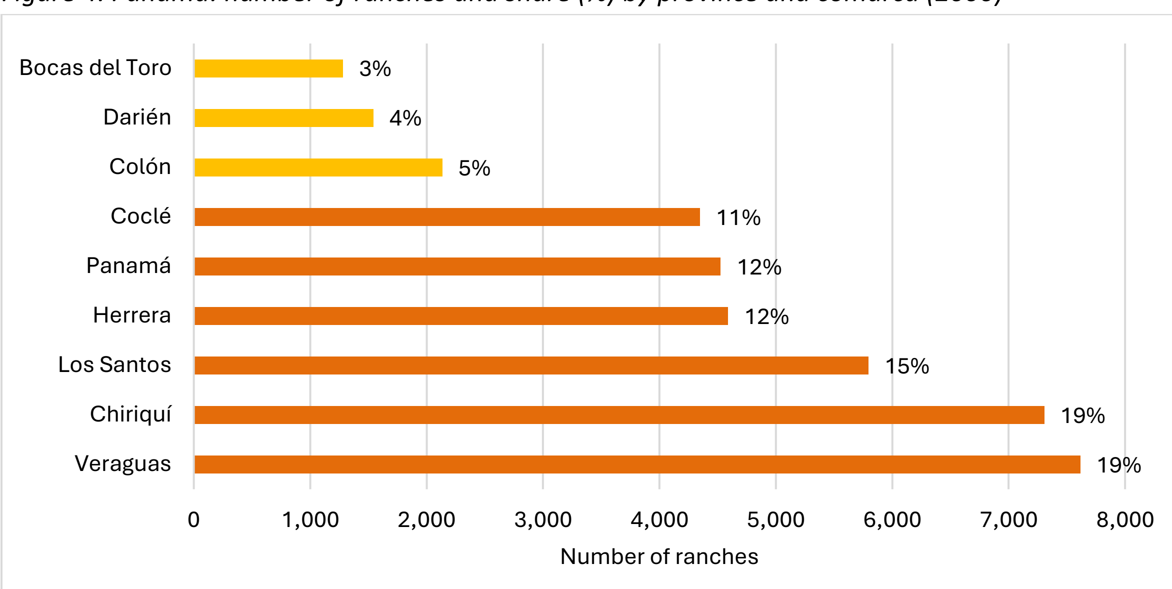


Source: Own from FAO data.

3.1.2. Number and size of ranches

In 2000, 39,205 farms were reported in Panama, distributed in eleven provinces. Most of them (87%) were in Veraguas (19%), Chiriquí (19%), Los Santos (15%), Herrera (12%), Panama (12%), and Cocle (11%) (Figure 4).

Figure 4. Panama: number of ranches and share (%) by province and comarca (2000)

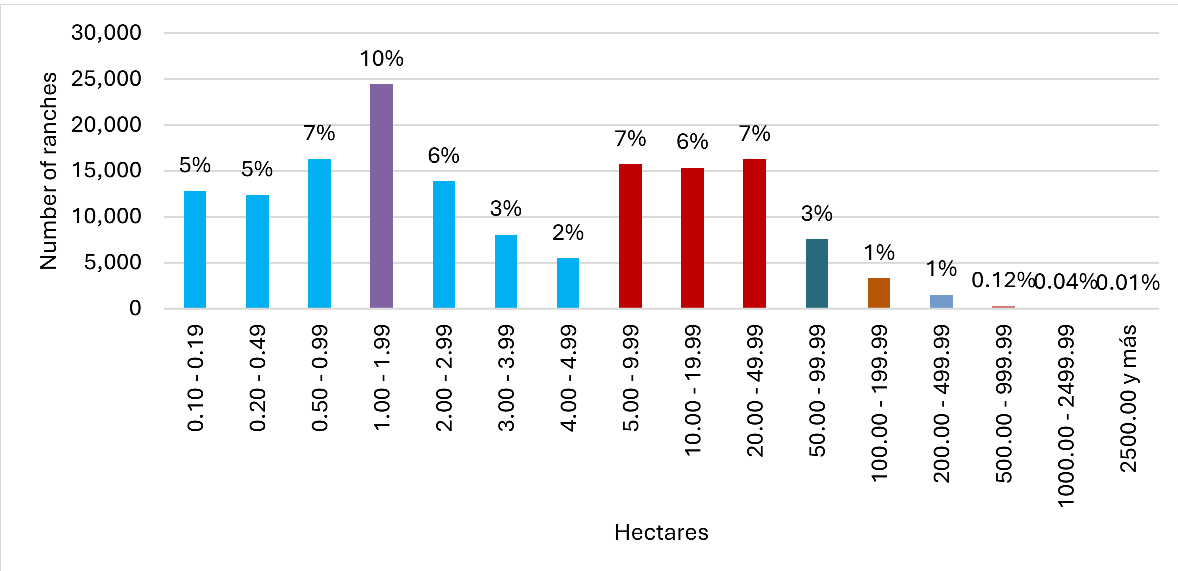


Source: Own from 2011 census data.

Most farms use traditional pastures, covering 65% of the total area dedicated to this activity. Natural pastures and improved pastures represented 18% and 17% of the total area dedicated to livestock in 2000.

Most livestock farms are smaller than 4.99 ha; this group represents 39% of all ranches, with the ones between 1 and less than 2 hectares being the most representative size (10%). Another group is represented by farms between 5 ha and 49.99 ha, totaling 20% of ranches registered in 2001 (Figure 5).

Figure 5. Panama: number of registered ranches by size (2001)[1]

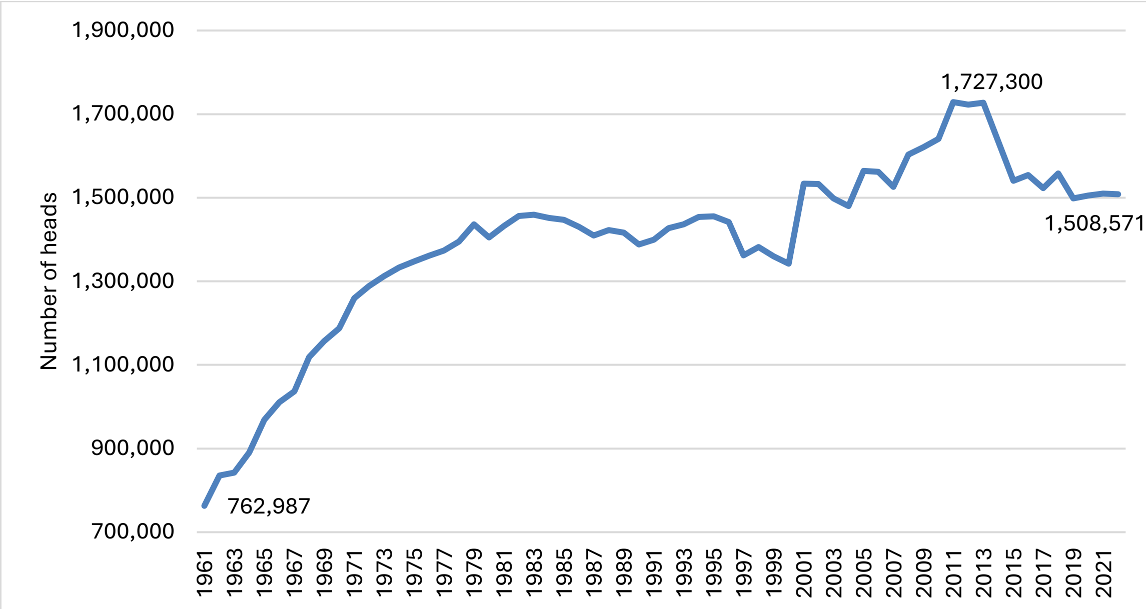


Source: Own from 2011 census data.

[1] Percentages show the share of the ranch size in Panama`s total livestock farms.

Even though there is no information on how the number of ranches has evolved, data on the number of heads of cattle shows a steady growth between 1961 and 2013. Although there were some years when the total number of animals decreased, the cattle livestock population more than doubled, going from 762,987 heads to 1,727,300. However, this trend was reversed from 2014; heads declined by 13% until 2022, with a current inventory of 1,508,571 animals (Figure 6).

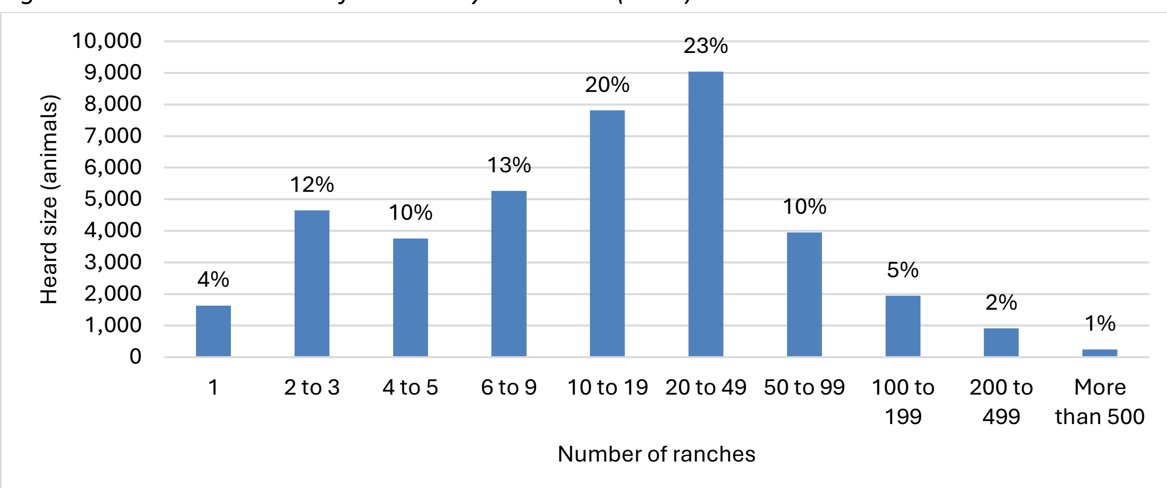
Figure 6. Panama: number of cattle heads (1961-2022)



Source: Own from FAO Stats.

The remaining exploitations are distributed by the number of heads they carry between those reporting just one animal and those with more than 500 heads. Most ranches have between 10 and 50 heads, with 43% of the exploitations belong to this group (Figure 7).

Figure 7. Panama: Number of ranches by heard size (2001)

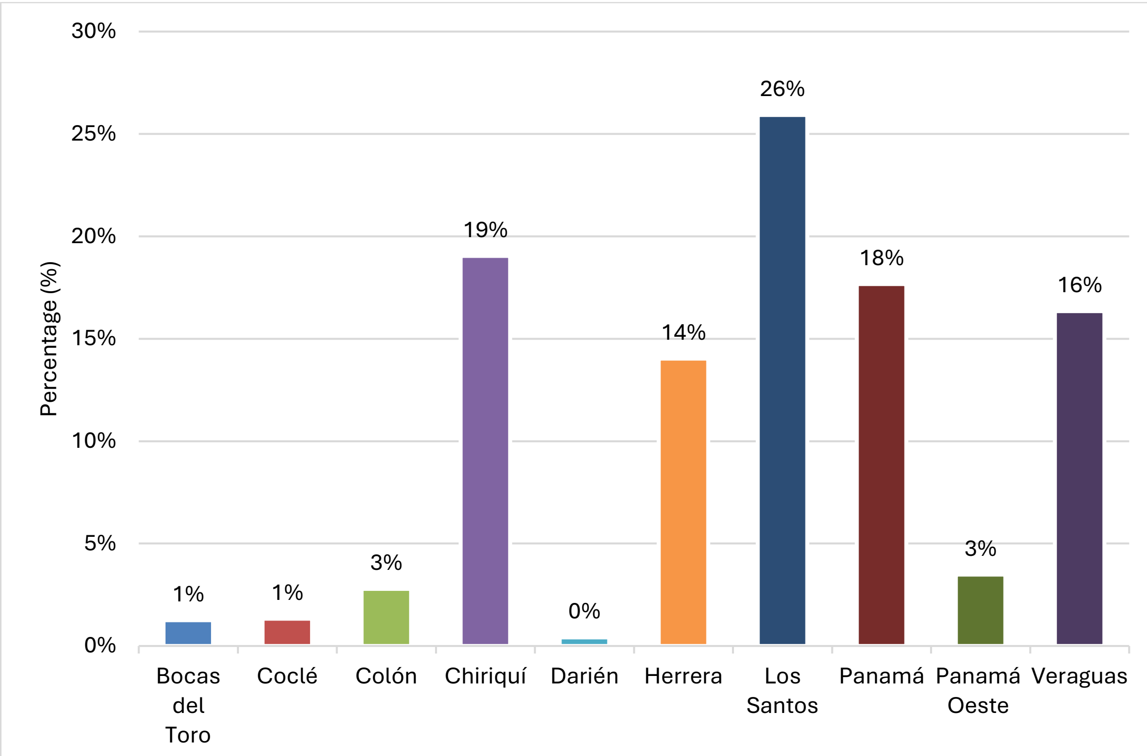


Source: Own from 2011 census data.

Interestingly, based on the census data available, it is estimated that 83% of the ranches do not carry any animals. If this is the case, the risk of leakage is relatively low in the industry since unexploited farms are available if production is to increase or to be transferred to other areas. The question is whether those farms have the potential to be as productive as the ones currently under production.

Finally, animal slaughter mirrors the head distribution around the country. Los Santos, Chiriquí, Panama, Veraguas, and Herrera are the regions with the highest share into total animals slaughtered (Figure 8).

Figure 8. Panama: distribution of cattle slaughter by province (average 2000-2020)



Source: Own from 2011 census data.

3.1.3. Prices

Producer prices for milk and fresh meat[3] were analyzed using data from FAOSTAT.

3.1.3.1. Meat producer prices

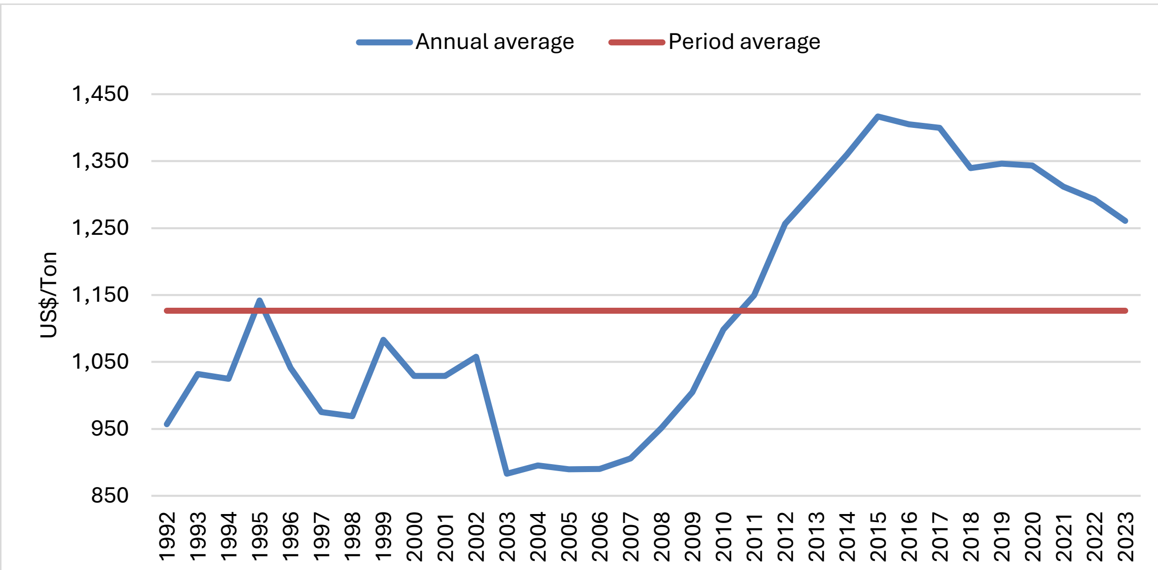
Data on the producer's price of meat is available from FAOSTAT from 1992 to 2023. Based on price trends, three growth periods are identified. The first runs from 1992 to 2005, characterized by fluctuating prices, with the average price of meat staying around $1000 per ton. The second period goes from 2006 to 2015, when prices increased steadily; at the end of this period the meat price per ton increased by 4.8%, reaching its maximum value at $1,417. A steady decrease in producer meat characterizes the third period (2016 – 2023), with the price level going down 14.5% (Figure 9).

[3] As defined by FAO: Meat of bovine animals, fresh or chilled, with bone in.

The downward trend observed in producer prices could be attributed to several market variables, such as the decrease in internal demand (analyzed in section 6.5.1), which is also reflected in lower imports (as discussed in section 6.4.1) and the reductions in pasture area (described before).

The declining trend in producer prices weakens the likelihood of leakage, as lower prices do not incentivize expanding production areas.

Figure 9. Producer price of meat (1992-2023)

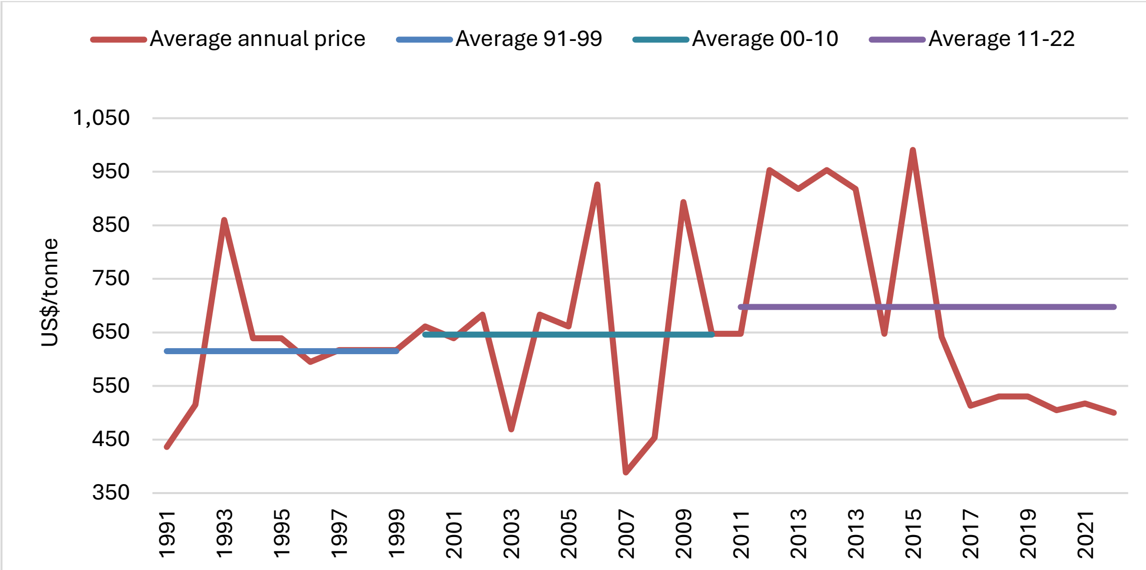


Source: Own based on FAOSTAT.

3.1.3.2. Fresh milk producer prices

Besides the annual fluctuations observed from 1991 to 2022, the price of fresh milk at the producer level showed an upward tendency until 2016, as shown in Figure 10. The average annual price between 1991 and 1999 was $615/ton, which increased 5% between 2000 and 2010, reaching a value of $646/ton at the end of this period; it grew an additional 8% between 2011 and 2022 when the average price reached $698/ton (these values are represented as straight lines in Figure 9). Nonetheless, from 2016, the price level has steadily decreased, reaching a minimum value of $500/ton in 2022, almost 30% lower than the average price of the previous years.

Figure 10. Fresh milk: average annual producer price (US$/ton) 1991-2022



Source: Own from FAOSTAT data.

3.1.4. International trade

Beef is among the six main agricultural products exported by Panama. The list includes bananas (with an average of $257 million between 2015 and 2019), coffee ($26 million), sugar ($23 million), beef ($27 million), pineapple ($15 million), and other fruits ($ 2 million) (Egas Yerovi et al., 2023).

Table 2 provides data on cattle trade, specifically export and import quantities and values over a 21-year period (2001-2022). Several immediate trends are noticeable: during the period 2001-2010, export quantities and values are relatively high. Imports remain low but show a gradual increase in quantity, though not necessarily in value. This could suggest growing domestic demand or a developing market for specific types of imported cattle. In the 2011-2022 period, we see a phase of more significant fluctuations. Export quantities and values become more erratic. Import quantities increase substantially, particularly after 2013, while import values remain comparatively lower, hinting at possible shifts towards importing less expensive cattle or changes in global market dynamics.

Table 2. Panama: Cattle Trade Export & Import Value (USD 1,000) and Quantity (Tons)

Year	Export Quantity	Export Value	Import Quantity	Import Value
2001	22,023	37,280	208	310
2002	7,169	13,310	204	206
2003	9,536	18,041	515	650
2004	7,627	13,242	214	199
2005	11,578	21,202	43	36
2006	16,878	30,638	35	81

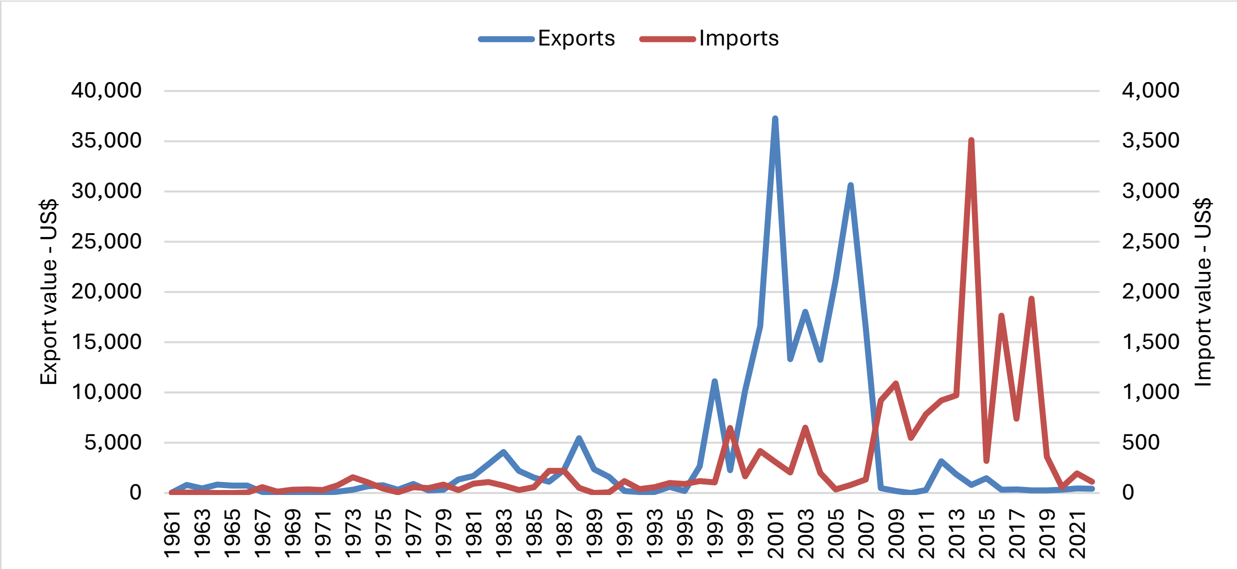
Year	Export Quantity	Export Value	Import Quantity	Import Value
2007	9,157	16,443	70	133
2008	587	479	220	921
2009	39	198	418	1089
2010	0	0	694	549
2011	388	296	597	784
2012	5,662	3,172	666	920
2013	3,948	1,868	956	971
2014	780	791	3,471	3,512
2015	2,375	1,462	168	318
2016	221	339	1,602	1,765
2017	341	353	472	739
2018	261	273	1,207	1,934
2019	326	258	303	361
2020	272	321	23	59
2021	516	455	85	194
2022	526	435	182	113

Source: Own from FAO Stats.

3.1.4.1. Meat trade

The trade balance for livestock was positive until 2006, with annual export values up to ten times higher than annual imported values. Afterward, exports decreased while imports grew at rate levels that reverted the historical positive trade balance, making Panama a net livestock importer. However, besides the observed growth in livestock imports, their maximum levels have yet to reach the export values observed before 2006, implying that livestock international trade flows have lost dynamism during the last 15 years (Figure 11).

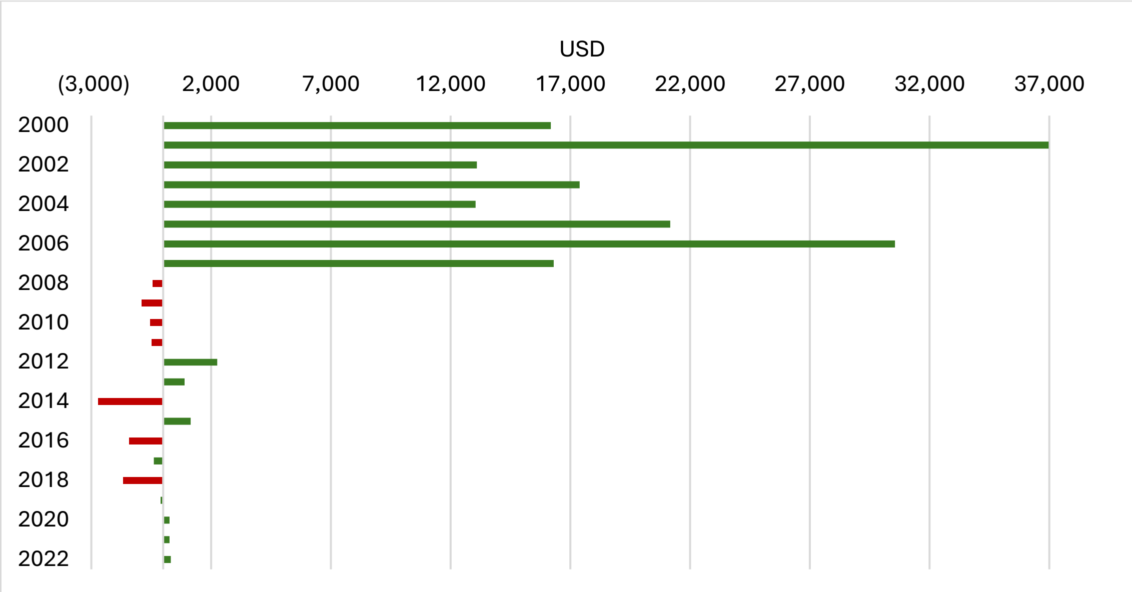
Figure 11. Livestock annual export and import values (US$) 1961 - 2022



Source: Own from FAO Stats.

This trend is more evident when the livestock trade balance is analyzed (Figure 12). Average net exports between 2000 and 2006 were around $20.5 million; however, the trade balance became negative afterward, averaging annual net imports of $365,000 between 2007 and 2019. It recovered afterward, with net exports reaching a net average yearly positive value of $282,000; this net export value is 73 times lower than the average observed at the beginning of the 2000s.

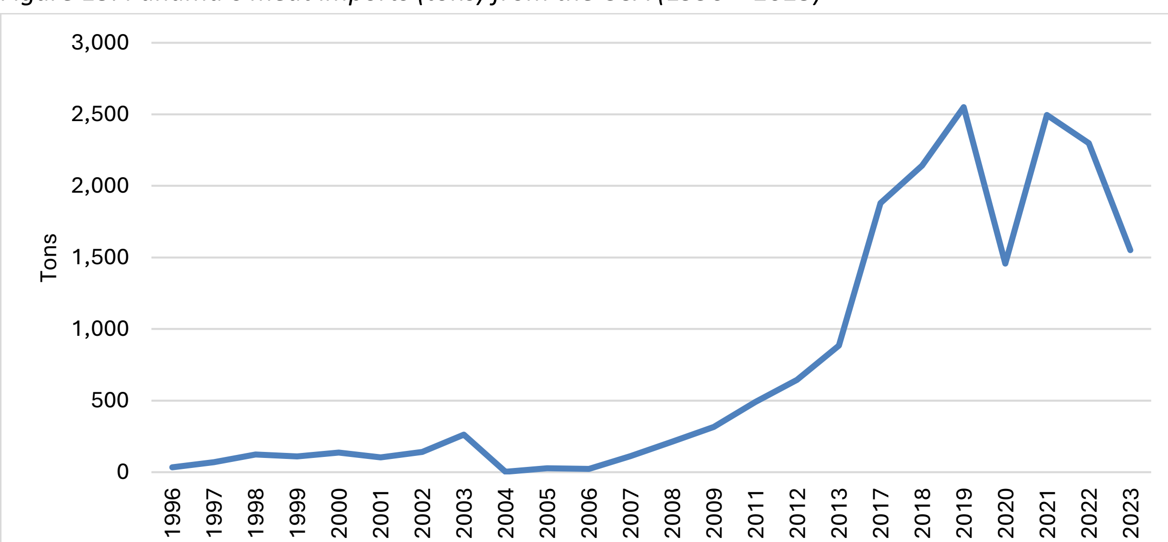
Figure 12. Livestock trade balance (US$) 2000 - 2022



Source: Own from FAO Stats.

The increase in imports (Figure 13) and the resulting negative trade balance in meat could be explained by the U.S.-Panama Trade Promotion Agreement (TPA) signed in June 2007, which entered into force in October 2012. The agreement aimed to eliminate tariffs and address barriers to U.S. exports, enhancing market access for American products in Panama. Following the implementation of the TPA, U.S. beef exports to Panama increased from 885 tons in 2013 to 1,551 tons in 2023, which accounts for a 75% rise.

Figure 13. Panama´s meat imports (tons) from the USA (1996 – 2023)



Source: Own based on FAOSTATS data.

Specifically for beef and milk, Panama's trade policy involves a combination of tariff reductions under trade agreements, mainly with the US, recognition of international sanitary standards, and applying import taxes and quotas to regulate the market. Import taxes protect both products; in the case of milk, the import tax ranges between 20% and 60%, and for beef, an import tax between 15% and 30% is applied to imports from other countries (Table 3).

Table 3. Panama: Meat Tariffs (2001–2022)

Year	Meat	Average tariff	Minimum tariff	Maximum tariff
2024	Meat of bovine animals, fresh or chilled.	25.0	15	30
2024	Meat of bovine animals, frozen.	23.3	15	30
2023	Meat of bovine animals, fresh or chilled.	25.0	15	30
2023	Meat of bovine animals, frozen.	23.3	15	30
2022	Meat of bovine animals, fresh or chilled.	25.0	15	30
2022	Meat of bovine animals, frozen.	23.3	15	30

Source: Own based on FATSTATS and WTO data.

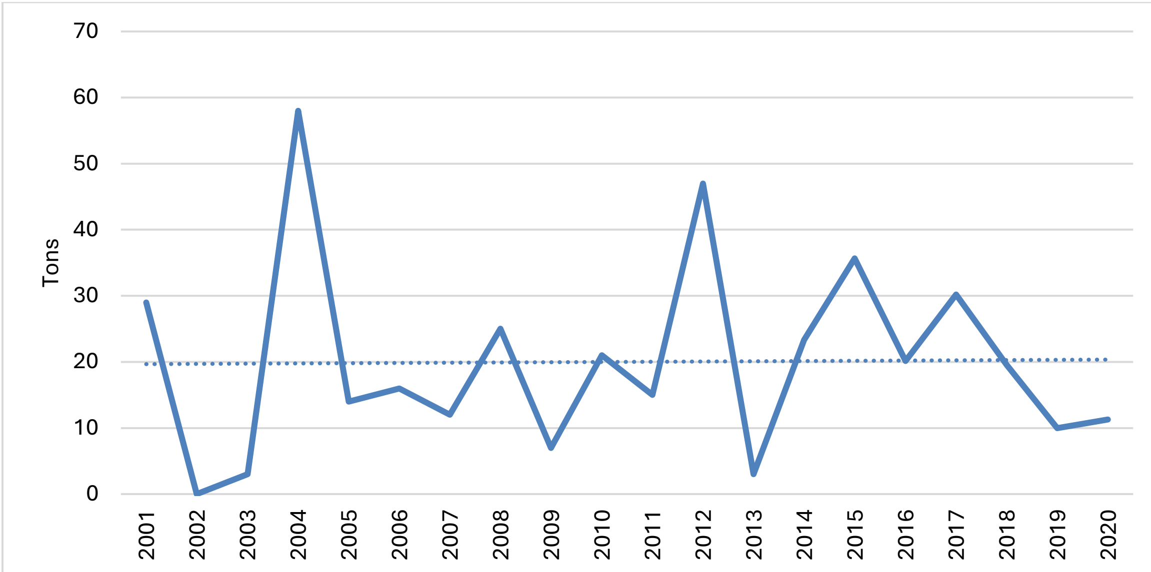
Given that Panamanian consumers perceive U.S. food products as high quality, wholesome, and reliable, the demand for meat imports is expected to keep growing. This trend decreases the likelihood of leakages since there is no incentive for local producers to increase their production levels.

3.1.4.2. Milk trade

International milk trade flows started in early 2000; before this year, some exports and imports were reported, but there was no continuity in the imports or export flows. The limited exports of milk can be explained by the production structure of this sector, with Panama having the lowest dairy production and export levels in Central America. Dairy farms are small and rely on family labor, and produce is intended to supply the local market (Ministerio de Comercio e Industrias, n.d.).

It can be observed that the exported quantity of milk does not show a growth path (Figure 14) and that it stayed on average at the same level between 2001 and 2020, varying around 20 tons yearly.

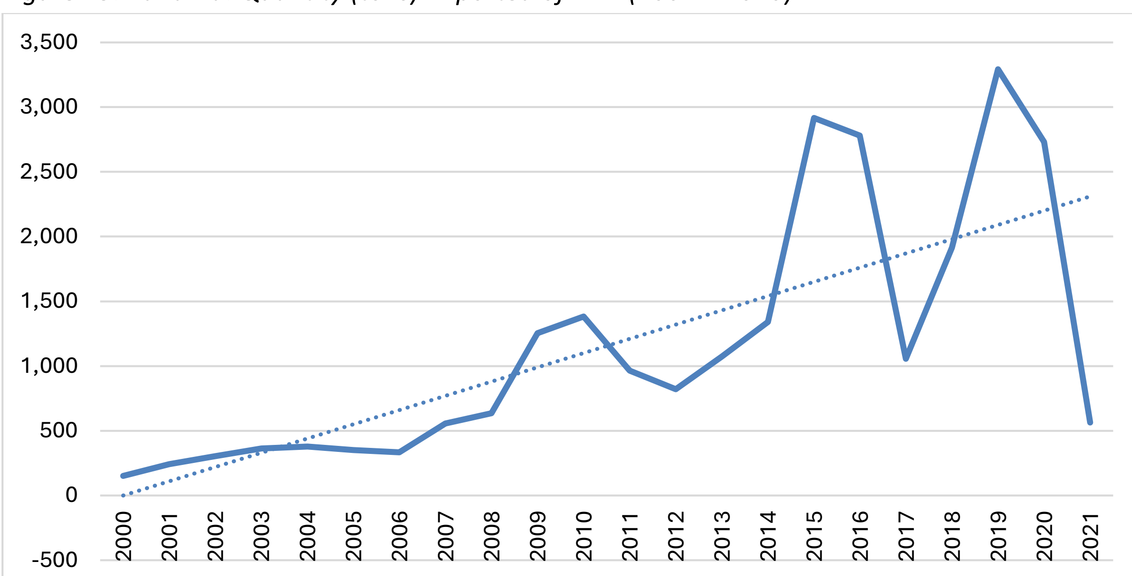
Figure 14. Panama: Quantity (tons) exported of milk (2001 – 2020)



Source: own from FAO Stats

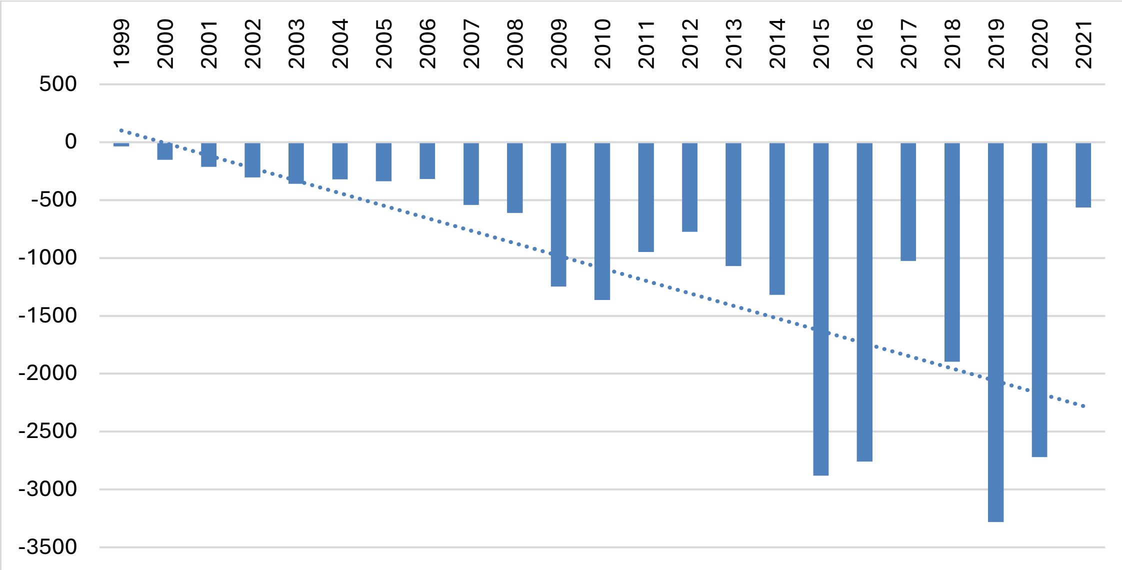
Unlike exports, import levels of milk have increased during the last 20 years (Figure 15). As a result, Panama`s trade balance for this product is negative, and the gap between export and import flows has grown increasingly (Figure 16).

Figure 15. Panama: Quantity (tons) imported of milk (2001 – 2020)



Source: own from FAO Stats

Figure 16. Panama: Trade balance (tons) of milk (2001 – 2020)



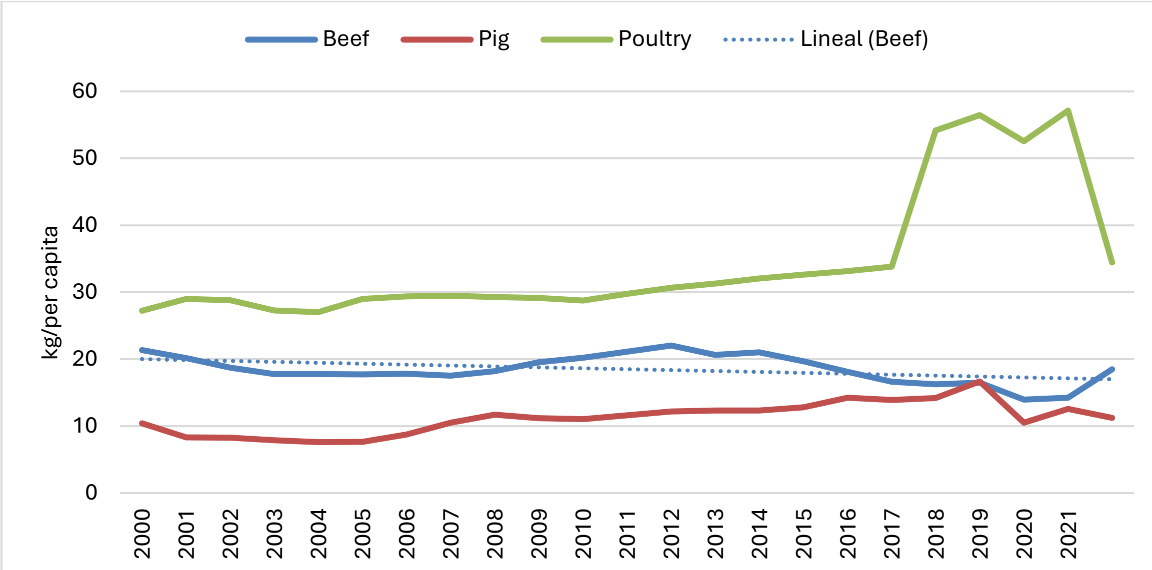
Source: Own from FAO Stats.

3.1.5. Consumption

3.1.5.1. Meat consumption

The total per capita average meat consumption in Panama was 65.2 kg in 2022; poultry leads the market with an average intake per person of 34.5 kg (52% share), followed by beef with 18.5 kilograms per capita (29%), and pig with 11.2 kg per person (17%). Between 2000 and 2022, beef consumption decreased slightly, going from an annual average consumption per person of 21.3 kg in 2000 to 18.5 kg in 2022 (Figure 17).

Figure 17. Panama: per capita annual consumption of meat (beef, pig and poultry (2000-2021)



Source: Own from FAO Stats.

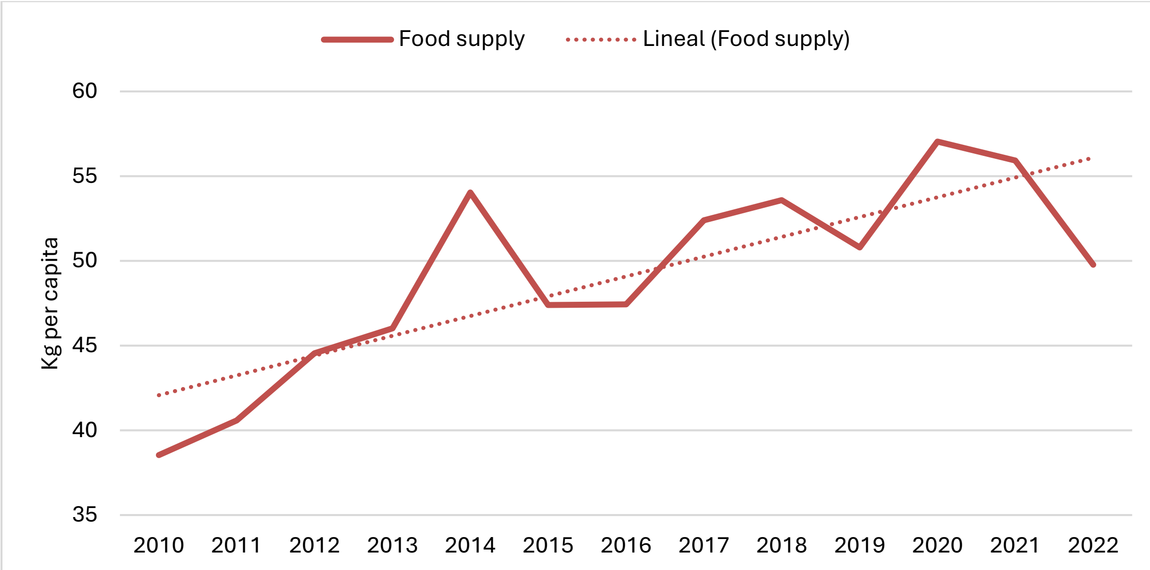
This decline in beef consumption, coupled with the behavior of market variables such as import levels and prices, reinforces the hypothesis that there is less pressure to expand production, thereby reducing the likelihood of leakage in beef production.

3.1.5.2. Milk consumption

Dairy consumption data is unavailable, so this analysis is based on FAO´s food supply balance table[4]. Contrary to beef consumption, the supply of dairy products in Panama has steadily increased from 2010-2022 (Figure 18). This trend must be analyzed in more detail to determine if increases in production or imports explain the observed growth in food supply.

[4] Actual consumption by individuals may be lower than the food supply figures indicate due to factors such as household storage losses, preparation waste, and plate waste.

Figure 18. Panama: annual supply of dairy products (excluding butter) per capita (2010-2021)



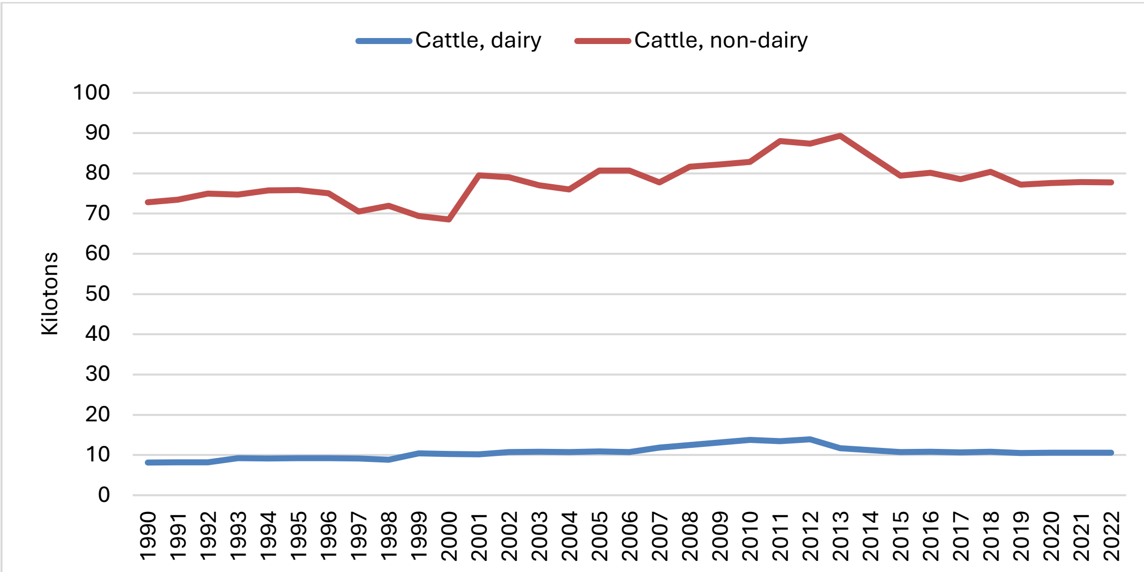
Source: Own from FAO Stats.

3.1.6. Livestock emissions

As previously observed, both the consumption and production of livestock in Panama exhibit a decreasing trend starting in 2013. This could partially explain the behavior of CH_4 and N_2O emissions.

The Figure 19 illustrates the total methane (CH_4) emissions from livestock, measured in kilotons, for two primary categories: "Cattle, dairy" and "Cattle, non-dairy," spanning the years from 1990 to 2022. It's evident that methane emissions from non-dairy cattle significantly surpass those from dairy cattle throughout the entire period. While both categories exhibit a slight upward trend in emissions over time, accompanied by some fluctuations, a closer look reveals a subtle decrease in methane emissions, particularly within the "Cattle, non-dairy" category, starting around 2013. This decline, although not drastic or sustained, could be attributed to various factors such as improved livestock management practices, increased productivity, shifts in the structure of the livestock sector, or reduced production due to lower prices, as previously discussed.

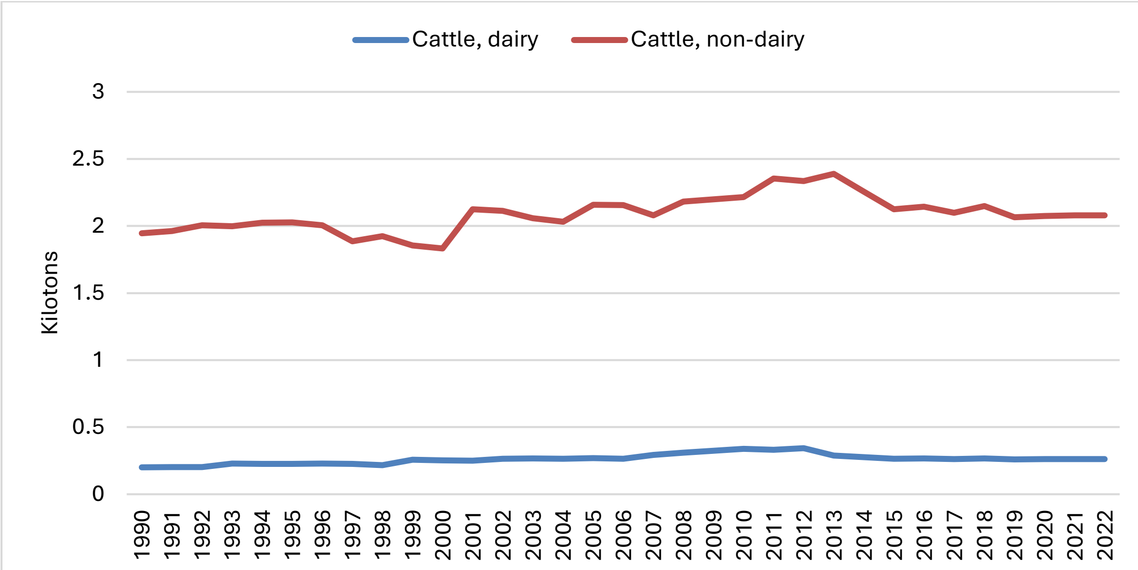
Figure 19. Livestock Emissions CH4



Source: Own from FAO Stats.

The Figure 20 shows the total nitrous oxide (N_2O) emissions from livestock, measured in kilotons, for the categories "Cattle, dairy" and "Cattle, non-dairy" from 1990 to 2022. While N2O emissions from non-dairy cattle consistently exceed those from dairy cattle throughout the entire period, both categories show a general trend of relatively stable emissions with minor fluctuations over time. However, a closer look reveals a noteworthy change: starting around 2010 for dairy cattle and 2013 for non-dairy cattle, a subtle but noticeable downward shift in emissions occurs. This decreases, while not a dramatic drop, suggests potential improvements in management practices or other factors influencing N_2O emissions. It's important to note that while this decrease is a positive sign, further investigation is needed to understand the underlying causes and ensure its continuation.

Figure 20. Livestock N2O Emissions



Source: Own from FAO Stats.

This section presents the main findings of the leakage analysis based on the data collected from landholders participating in the ARC Restaura Azuero project.

3.2. Econometric analysis

The results across all six ARIMA models (Table 4) indicate that the main driver of pasture area expansion is the dynamics of the cattle herd. In every specification, the number of heads of cattle (in second differences) shows a positive and statistically significant effect on pasture area, with consistent coefficients ranging from 0.22 to 0.24. This means that increases in livestock herds translate directly into pasture growth, reinforcing the interpretation that there is a risk of leakage: if cattle production expands, it is highly likely that additional pasture will be cleared, even when other factors remain constant.

For instance, a coefficient of 0.24 implies that when the second difference in herd size (d2ln_number_heads) increases by one unit, the growth rate of pasture area (dln_pastures_area) rises by 0.24 units, holding other variables constant. Expressed as an elasticity, a 1% acceleration in the number of cattle is associated with a 0.24% increase in pasture expansion. In other words, when herd growth accelerates, pasture area tends to expand proportionally, though at a smaller magnitude. This highlights that even if restrictions or conservation programs are applied in certain areas, structural pressure remains to expand pastures elsewhere if livestock demand persists or grows- constituting a clear mechanism of spatial leakage.

In contrast, other explanatory variables—including domestic beef prices, chicken prices, international meat trade (imports and exports), and the dummy variable for the Free Trade Agreement (FTA) with the United States—do not exhibit significant effects on pasture area. For example, the FTA dummy has a very small and statistically insignificant coefficient (0.0011, p = 0.968). This might suggest that the enforcement of the agreement had no immediate impact on pasture dynamics. This result can be explained by the fact that livestock was one of the most protected sectors under the FTA, and tariff reductions were not implemented immediately, which muted any short-term land-use response.

Table 4. Econometric model results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Number of heads (SOD)	0.240** (3.07)	0.244*** (5.42)	0.222*** (4.40)	0.234** (3.09)	0.242*** (4.29)	0.226*** (3.40)
Domestic meat price (Logaritm)	0.00165 (1.00)					
Meat price index (SOD)		0.00234 (0.15)				
Domestic chicken price (First differences)	-0.0194 (-0.35)	-0.00841 (-0.13)				
TLC USA (FOD)	0.00116 (0.04)	0.00387 (0.00)				
Meat cattle imports quantity (FOD)			-0.000846 (-0.74)			
Meat cattle imports value (FOD)				-0.000812 (-0.38)		
Meat cattle exports quantity (Logaritm)					-0.000782 (-0.10)	
Meat cattle exports value (FOD)						-0.00333 (-0.21)
Constant	-0.00985 (-0.91)	0.000612 (0.40)	0.00106 (0.43)	0.000979 (1.01)	0.00729 (0.11)	0.00111 (0.51)
ARMA						
L.ar	0.709 (1.50)	-0.121 (-0.18)	-0.0424 (-0.05)	0.810 (1.93)	0.814* (2.52)	-0.0191 (-0.03)
L.ma	-1.000 (.)			-1.000 (.)	-1.000 (.)	
Sigma						
_cons	0.00584*** (6.04)	0.00641*** (8.69)	0.00617*** (7.15)	0.00588*** (9.28)	0.00582*** (7.00)	0.00621*** (6.50)
Observations	28	28	25	25	26	25
Log Likelihood	103.4	101.7	91.75	92.29	96.25	91.58

AIC	-192.8	-189.3	-173.5	-174.6	-182.5	-173.2
BIC	-183.5	-180.0	-167.4	-168.5	-176.2	-167.1

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
SOD: Second order differences; FOD: first order differences

From the perspective of the time-series structure, the ARIMA models capture both persistence and short-term shocks in the data. In several specifications, the autoregressive terms are relatively strong (0.71 to 0.81), meaning that changes in pasture area tend to carry over from one period to the next, reflecting inertia in land-use decisions. At the same time, the moving average terms help filter out random fluctuations or "noise" in the data. Put simply, the model adjusts for short-term bumps and irregularities, allowing a clearer picture of the underlying trend in pasture dynamics.

Overall, the evidence confirms that livestock herd growth is the primary factor linked to pasture expansion, while prices, trade, and policy shocks play only a minor role in the short run. For the project, this implies that interventions focused on stabilizing or reducing herd expansion are critical to managing leakage risks. If herd numbers continue to rise, pasture area is very likely to expand, regardless of external trade conditions or price signals. Model comparison based on information criteria suggests that specifications with fewer variables perform better. Model 1 yields the lowest AIC (–192.8) and BIC (–183.5), followed closely by Model 5, which also demonstrates a significant autoregressive component. Models 3, 4, and 6 present weaker performance, with higher AIC and BIC values, while Model 2, despite having fewer variables, is slightly less efficient than Model 1. Overall, Model 1 appears to strike the best balance between parsimony and explanatory power, while Model 5 stands out for its significant AR term.

From the trend analysis results shown in the previous section, it was observed that in Panama the herd size has decline over the period 2010–2021, from 1.69 million heads in 2010 to 1.50 million in 2021 (a reduction of approximately 11%). From a leakage perspective, this means that efforts to restrict pasture expansion in certain areas (e.g., through conservation programs, protected areas, or land-use regulations) could be undermined if national herd growth continues unchecked. Farmers may respond to livestock demand by expanding pastures elsewhere, shifting pressure geographically rather than reducing it—a classic form of leakage, suggests that the risk of the livestock frontier increasing has been limited in the recent period, because the growth in herd size, has decreased. However, the model's positive coefficient warns that if cattle numbers resume a growth trajectory in the future, pressure on pastures and leakage risk could be reactivated significantly.

To address this risk, policies need to go beyond geographically specific conservation measures and target the structural relationship between herd size and land demand. This could include:

- Promoting intensification and productivity gains: Increasing meat or milk yields per hectare can help decouple production growth from land expansion, reducing the elasticity link between cattle numbers and pasture growth.

- Aligning livestock incentives with sustainability goals: For instance, credit, subsidies, and technical assistance should be conditioned on sustainable grazing practices, rotational systems, or silvopastoral models that increase output without requiring new land.
- Strengthening land-use governance: Zoning regulations and enforcement mechanisms are necessary to ensure that increases in livestock demand do not translate into invasion on forested or high-biodiversity areas.
- Monitoring and early warning systems: Given the positive coefficient, if cattle numbers rise again in the future, there is a clear risk of renewed pasture expansion. Integrating herd dynamics into monitoring frameworks would allow policymakers to anticipate and manage potential leakage before it becomes significant.

In summary, the elasticity highlights that leakage prevention in Panama depends not only on where conservation policies are applied, but also on how livestock policies are designed at the national level. Integrating herd management, productivity improvements, and stronger land-use regulation is essential to break the link between cattle growth and pasture expansion, ensuring that conservation gains in one area are not offset by losses elsewhere.

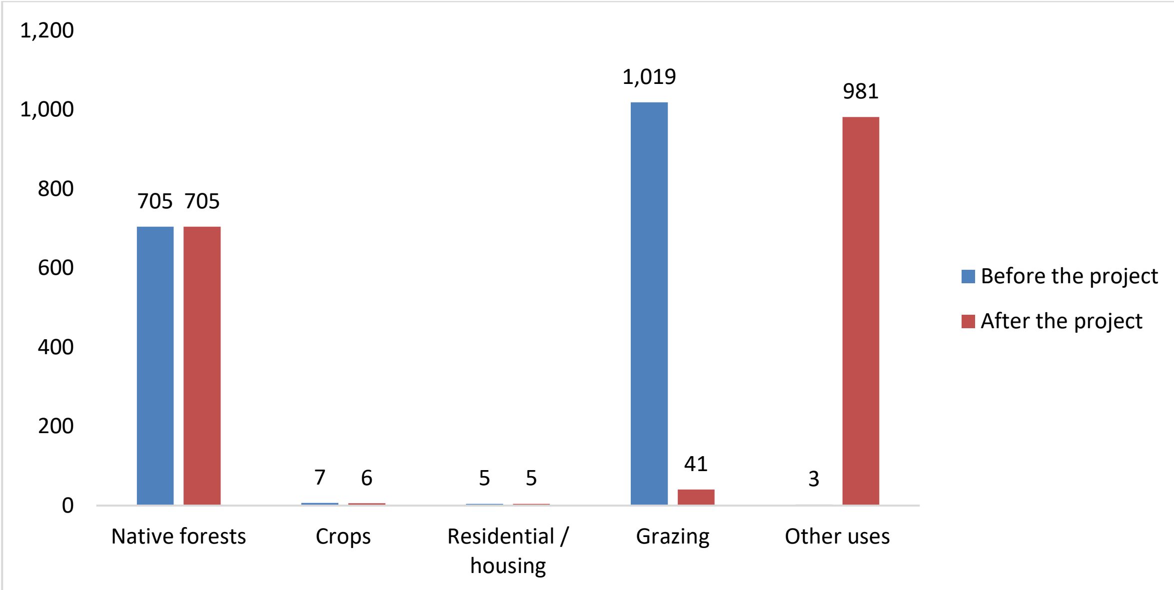
3.3. Qualitative analysis

This section presents evidence from primary data collected through structured surveys with project participants, focusing on the extent of land-use reallocation, the role of livestock within household economies, and the implications for leakage risk. The analysis highlights how landowners have transitioned from traditional cattle-based systems toward reforestation, while also exploring the degree to which livestock activities persist, shift, or decline in response to project requirements. By combining quantitative indicators of land and livestock use with qualitative insights into household strategies, the section provides a nuanced perspective on the transformations occurring within the project landscape and their broader relevance for sustainable rural development.

3.1.2. Land-Use transformations and livestock dynamics

Most landowners manage between 8.9 and 188.1 hectares, with the 27 producers collectively holding a total of 1,737 hectares. Prior to the project, only one producer used their land entirely for restoration and forest regeneration. As a result, nearly 96% of the land that was previously used for grazing by all producers is now being transitioned to reforestation (Figure 21).

Figure 21. Land use distribution in the Project Area: before and after project implementation (Hectares)



In terms of leakage risk, the land-use changes observed before and after the ARR project reflect a substantial reduction in areas dedicated to grazing, decreasing from 1018.59 ha to 40.87 ha, which represents a drastic transformation of the productive system. This reduction suggests that a significant portion of the land previously used for livestock activities was withdrawn from uses that potentially generate emissions. Part of this area was reclassified under "other uses" (increasing from 2.5 ha to 981.22 ha), which, according to the survey, was dedicated to reforestation, indicating a shift aligned with the ARR project's objectives. In addition, there is no change in native forests (704.74 ha) neither in fallow land (0 ha), which may also be interpreted as a signal of ecosystem recovery or stabilization.

Taken together, these changes support the hypothesis that livestock activities were not displaced to other areas within the project landscape, thereby significantly reducing the risk of internal leakage.

On average, producers reported managing 48 heads of cattle, totaling approximately 1,304 heads annually across all respondents during the 2020–2024 period within the ARR project area. Of this total, around 89% was intended for commercialization and 13% for self-consumption. Among the 27 participants, the vast majority were engaged in fattening operations, with 20 individuals (74%) reporting this activity. Breeding was also relevant, present in 15 cases (56%), whereas milk production was considerably less common, observed in only 3 cases (11%).

From a leakage risk perspective, this productive profile presents favorable elements but also certain challenges. The high prevalence of fattening activities is advantageous for the project, as this stage represents the final phase of the cattle production cycle. Consequently, if fattening activities are reduced or discontinued as part of the measures adopted under the ARR project, it is less likely that animals will be transferred to other properties to continue their growth. This condition supports the argument that livestock sales were likely directed toward slaughter, thereby reducing the risk of emission leakage.

However, the significant presence of breeding activities in more than half of the cases warrants careful evaluation. As the initial stage in the production cycle, breeding poses a higher risk of indirect leakage if other properties outside the project area increase their output to compensate for the reduced supply. Such displacement of production could lead to emissions beyond the project boundaries, highlighting the need for additional mitigation measures or more detailed analysis regarding the destination of the young animals sold.

As for milk production, its low prevalence within the sample implies that the associated risk is marginal. While in some contexts this activity may be linked to land-use pressures, in this case its limited presence among participants minimizes its relevance in terms of leakage risk.

Regarding pastureland productivity, most participants within the project area (17 out of 27) reported that the land's carrying capacity remained unchanged, while 7 indicated an increase and only 3 observed a decrease. This perception aligns with the quantitative data collected, which shows an average stocking rate of 1.3 heads of cattle per hectare in the project area (indicating moderate and stable grazing pressure on forage resources). In the mitigation area, a similar pattern emerges, with the majority (14 respondents) perceiving stability, while 5 noted an increase and 2 reported a decrease. This is consistent with a slightly higher average stocking rate of 1.8 heads per hectare in the mitigation area. Some participants described mixed experiences, such as increases in previous years followed by recent declines, which may be attributed to climatic events, land-use changes, or specific management decisions.

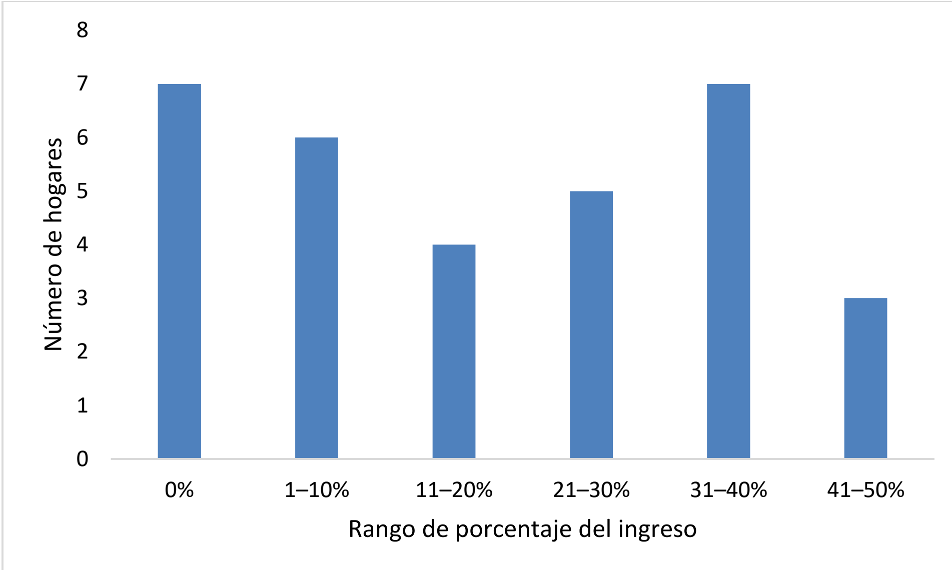
From a leakage risk perspective, this scenario is favorable. The reported stability or slight increase in carrying capacity, combined with moderate stocking levels, suggests that there has been no excessive pressure on areas outside the project boundaries or significant displacement of livestock activities. On the contrary, the data indicates a potential improvement in land use, with no clear signs of harmful intensification that could compromise the environmental goals of the project.

3.1.2. Economic importance of the ARR farm for households and their adaptive capacity

Figure 22 reveals the relative contribution of the ARR farm to household earnings share. For a significant number of households, this farm does not constitute a relevant source of income: seven households reported receiving no income (0%) from it, while six others indicated that income from the farm represents only between 1% and 10% of their total household earnings. This suggests that, for many, the farm is either underutilized or plays a secondary role in household economic strategies, possibly due to limited capital, time constraints, lack of infrastructure, or the prioritization of other economic activities.

Conversely, there are cases in which the farm constitutes a substantial portion of household income. Specifically, five households reported that the farm contributes between 31% and 40% of their total income, while four households stated that its contribution exceeds 40%. For these families, the farm holds considerable economic weight, which may indicate more intensive land use, greater dependence on productive activities linked to the property, or a lower level of income diversification.

Figure 22. Relative Contribution of the ARR Farm to Household Earnings Share



From a social perspective, this distribution has important implications for the potential impact of the ARR project on participating households. In cases where the farm plays a central role, the project may generate significant transformations in quality of life, food security, economic stability, and rural employment opportunities. These households are likely to be more sensitive to the changes promoted by the project and more vulnerable if the income associated with the farm is disrupted.

In contrast, for households with little or no economic dependence on the farm, the direct social benefits of the project may be limited , unless the implementation of the payment for environmental services mechanism has a significant impact on household income, or complementary mechanisms such as training programs or community engagement activities are activated to ensure their inclusion.

The data collected shows that, in response to the restriction on using ARR project lands for livestock activities, some households have adopted various economic adaptation strategies. However, a percentage of households have either remained exclusively dedicated to the project (14.8%) or have reported uncertainty about how to adapt (7.4%). The most common strategy has been relocating livestock activities to other farms, mentioned by 37% of households. Another portion has continued agricultural activities on unrestricted land (18.5%), while a smaller group has diversified into new forms of production such as pig or poultry farming, or the construction of storage sheds for subsistence use (7.4%). A minor percentage reported shifting their focus to pre-existing sources of income, such as small businesses or formal employment (14.8%).

This scenario suggests that while some households possess the means and resources to reconfigure their productive activities (e.g., through access to other landholdings), others lack clear alternatives and depend solely on the project or informal income sources. This contrast reveals an unequal adaptive capacity among households, likely influenced by factors such as asset ownership, educational level, family networks, or previous experience in alternative economic activities.

Regarding non-productive income, the data shows that 63% of households report receiving no income beyond what is generated through their economic activities (whether agricultural, livestock-related, or linked to the project). Only 37% mentioned some form of complementary income, such as student scholarships, property rentals, salaries from other household members, pensions, or state support programs such as “100 a los 70.”

3.1.3. Operational challenges, capacity gaps, and incentives for continued participation in the ARR project

The analysis reveals that most participating households face economic and operational challenges in managing their ARR farms. Approximately 38.5% of households reported difficulties related to bank loans or financing, highlighting a structural concern regarding access to financial resources to sustain productive activities. This is followed by challenges related to securing labor and maintaining livestock, directly or indirectly mentioned by around 26.9% of households. Other recurrent issues include the distance to the farm, the cost of leasing, lack of follow-up by PONTERRA, and problems accessing agricultural inputs. A small group (7.7%) reported no issues or noted benefits from participating in the project.

Farms used for leakage mitigation face similar challenges, albeit with a broader dispersion of responses. The most frequently cited issues include the cost of land leasing, insufficient labor, and water scarcity, as well as difficulties in transferring cattle to these newly designated areas. Overall, at least 30% of households identified operational or logistical complications, such as limited access, steep terrain, or inadequate livestock management by third parties. About 19% of respondents indicated they had not faced significant management problems, which may suggest that some farms enjoy better access, infrastructure, or more stable arrangements with third-party managers. However, cases of economic loss due to poor management by third parties or uncompensated relocation costs indicate that the leakage mitigation model still lacks robust technical and financial support mechanisms.

Regarding improvements in farm management, 98% of households expressed interest in receiving training on sustainable production practices. However, preferences for the training format varied: 7.7% preferred classroom sessions, 15.4% favored internet-based videos, and a significant 75% showed a clear preference for hands-on, field-based workshops, underscoring the importance of practical, context-sensitive learning in rural settings.

In terms of conditions necessary for continued participation in initiatives like ARR, responses indicate a strong emphasis on financial stability and project transparency. About 35% of participants stressed the importance of timely payments, economic profitability, and ensuring the maintenance of household income. Participants also cited the need for technical assistance, involvement in decision-making, and visible reforestation outcomes. Another 28% pointed to adequate economic compensation, legal security of contracts, active participation, and environmental conservation as essential factors for ongoing engagement. These findings underscore the need to strengthen institutional credibility, financial planning, and social inclusion within the ARR project model to retain household participation.

Finally, regarding motivation for continued participation in the ARR project, carbon credits emerged as the most frequently cited incentive, directly or indirectly mentioned by 61% of households. However, in most cases, participants expressed concern that the current credit value is too low, and that increasing the amount received or the market value of credits would be critical for their continued involvement.

Other motivating factors included the increased value of land linked to an environmental project (11%), support for community and rural infrastructure (e.g., roads, access), and the potential to receive additional payments for biodiversity or sustainability certifications. These findings suggest that the ARR project could have greater impact if it evolves into a platform that delivers broader environmental and social co-benefits beyond basic payments for ecosystem services.

4. Main findings

This report analyzes the economic landscape of Panama's livestock sector, focusing on its relevance to a carbon project aiming to reduce greenhouse gas emissions through afforestation, reforestation, and revegetation (ARR). Overall, it is concluded that while the existing capacity for expansion within the current land use suggests opportunities for mitigation, further research, particularly on specific data points, is necessary to strengthen the conclusions and formulate precise recommendations.

The main findings by topic are the following:

a. Livestock sector overview

Panama's livestock sector, while relatively small compared to its GDP (2.8% between 2010-2019), plays a significant role in certain provinces. Cattle farming dominates, with a focus on domestic consumption. Dairy farming also contributes substantially to rural livelihoods.

Pastureland covers approximately 20% of Panama's total land area. While the pasture area expanded until 2013, it has since slightly declined. The reasons for this decline are unknown and require a more profound analysis based on primary data.

Most livestock farms are small, and a significant proportion are currently not in use. This presents a potential buffer to limit land-use change driven by increased livestock production.

b. Market dynamics

Beef consumption has slightly declined in recent years, potentially reducing pressure on land use change for beef production. Dairy product supply has been steadily increasing, but the data available does not allow for determining if this growth stems from increased domestic production or imports. Further investigation is needed. In addition, Panama has a positive but declining livestock trade balance, suggesting weakening export performance.

c. Carbon leakage risk

The literature review determined that leakage is highly context-specific, influenced by factors like market dynamics, land value, and the project's integration with surrounding systems. Larger-scale projects with careful design are less susceptible to leakage. This result is general and not specific to Panama. However, similar findings are expected from the analysis in the second phase of this project, based on primary information.

From the market dynamics analysis, which is based on secondary data, it is concluded that the risk of leakage is relatively low for three main reasons: (i) underutilized land (83% of the ranches do not carry any animals); (ii) declining beef consumption and prices; and (iii) decreasing trend in producer prices for meat and dairy. However, further investigation, including primary data collection, is needed to confirm these findings.

Finally, the ARIMAX model indicates that herd dynamics are the primary driver of pasture expansion, with the number of cattle heads (d2ln_number_heads) showing a positive and statistically significant effect, while relative prices and the Free Trade Agreement dummy were not significant. This suggests that pasture growth is largely influenced by herd size rather than short-term market fluctuations or trade policies. The declining trend in cattle numbers between 2010 and 2021 corresponds with limited pasture expansion and a reduced risk of spatial leakage during this period. Based on these findings, policy interventions aimed at maintaining or increasing conservation outcomes should focus on managing herd growth and promoting sustainable livestock practices. Monitoring herd dynamics and integrating conservation incentives directly linked to herd size can help prevent potential leakage in the future, ensuring that restoration and pasture management programs achieve their intended environmental benefits.

However, the results of this model must be considered with caution given its limitations. One key limitation of the ARIMAX model is the limited number of observations, as the dataset spans only 30 years. This restriction constrained the number of explanatory variables that could be included without risking overparameterization, potentially omitting factors that also influence pasture expansion. Another limitation concerns the excluded variables, particularly relative prices and trade effects, which were not statistically significant in the model. This lack of significance may result from data limitations or the aggregated nature of the series, rather than indicating a true absence of influence on pasture growth.

The stationarity transformations applied to the variables, including first- and second-order differencing, may also constitute a limitation. While necessary to satisfy model assumptions, these transformations can remove long-term trends or structural relationships, reducing the model's ability to capture persistent effects or potential cointegration among variables. Additionally, the ARIMAX model relies on the assumption of linear relationships between variables. This may limit its capacity to fully capture non-linear dynamics or complex interactions between herd size, market prices, and policy interventions.

Finally, the model does not explicitly account for external shocks such as extreme weather events, disease outbreaks, or sudden policy changes, all of which could significantly impact pasture expansion and herd dynamics but are not reflected in the historical data.

5. Mitigation strategies and recommendations

Based on the results of both the description livestock sector, the econometric analysis and the qualitative assessment of the ARC Restaura Azuero Project, several recommendations can be drawn to enhance the effectiveness of ARR interventions and reduce potential carbon leakage.

The ARIMAX model indicates that herd dynamics are the primary driver of pasture expansion, while relative prices and trade policies had little influence. Therefore, conservation programs should focus on herd management practices, including monitoring herd growth and promoting sustainable livestock strategies. By targeting herd dynamics, projects can reduce pressure on pastures and minimize the risk of spatial leakage in the future.

The presence of numerous underutilized farms suggests that additional livestock production could be accommodated within existing land resources without triggering deforestation. Project design should integrate production adjustments with restoration goals to optimize land use while avoiding new pressures on forested or high-carbon areas.

To improve the accuracy of leakage assessments, implementers should establish a robust verification protocol that triangulates multiple sources of information. This includes confirming whether livestock activities were effectively relocated, discontinued, or sold for slaughter. Such verification reduces reliance on assumptions that could overestimate leakage and strengthen the credibility of project outcomes.

Data collection processes should be improved through pilot surveys and technical review sessions with the data collection team before fully implementation. Early identification of survey design issues, enumerator interpretation, or misclassification of livestock activities will enhance data quality, reduce errors, and provide more accurate leakage estimates.

Finally, the qualitative analysis supports the conclusion that the ARR Azuero Project has not resulted in significant carbon leakage, as evidenced by the reduction in grazing areas, reclassification toward carbon-sequestering uses, stable native forest cover, and moderate stocking rates. Project implementers should continue to integrate field observations with quantitative monitoring, allowing for adaptive management that responds to changing herd sizes, market conditions, or policy environments, thereby sustaining environmental benefits over time.

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7. Annex

Annex 1. Questionnaire Used for Data Collection

Annex 2. Spreadsheet Calculations Supporting Leakage Analysis

Annex 3. Do-file econometric analysis

Buenos días/ buenas tardes. Mi nombre es ___________ y formo parte de CONSERVATION STRATEGY FUND, una organización que aplica herramientas y conocimientos económicos para identificar e informar soluciones de conservación a desafíos ambientales. Actualmente, estamos colaborando con PONTERRA en el proyecto de restauración que se lleva a cabo en la Península de Azuero, Panamá denominado ARC Restaura Azuero. Como parte de esta iniciativa, estamos realizando un análisis económico del sector ganadero en Panamá, con el objetivo de fortalecer el argumento a favor de la reducción del riesgo de fugas en el contexto del proyecto de forestación, reforestación y revegetación (ARR). Para lograrlo, necesitamos su valiosa colaboración completando una encuesta totalmente anónima. Los resultados serán utilizados exclusivamente para los fines mencionados y serán tratados con la más estricta confidencialidad. La encuesta tiene una duración aproximada de _____ minutos y su participación será de gran ayuda para el éxito de esta iniciativa.

¿Le gustaría participar? Si ☐ No ☐

Código encuesta: Iniciales del nombre y apellido del encuestado

I. INFORMACIÓN REQUERIDA PARA LA APLICACIÓN DE LA METODOLOGÍA VDM

Esta sección consulta preguntas para el área del proyecto ARR:

1. (CUALI- V1) ¿Qué tamaño (*hectáreas*) tiene la finca que hace parte del proyecto ARR?

2. (CUALI- V2) Especifique PARA EL CASO ANTES Y DESPUÉS DEL PROYECTO, ¿qué área y/o porcentaje de la FINCA estaba dedicada a cada uso? (*Diligencia el siguiente cuadro para responder esta pregunta*):

Antes del proyecto ARR		**Después del proyecto ARR**	
Uso	**% del total o Ha**	**Uso**	**% del total o Ha**
Descanso		Descanso	
Bosques nativos		Bosques nativos	
Cultivos		Cultivos	
Habitacional/ Vivienda		Habitacional/ Vivienda	
Pastoreo		Pastoreo	
Otros usos		Otros usos	

Antes del proyecto ARR		Después del proyecto ARR	
Uso	**% del total o Ha**	**Uso**	**% del total o Ha**
¿Cuáles otros usos?		¿Cuáles otros usos?	

3. (VMD- V3, VDM- V7) En el siguiente cuadro especifique la producción y el rendimiento de los productos y/o servicios que se han generado en la finca en los años 2020 a 2025 en el área del proyecto. *Replique el cuadro para cada producto*.

Año	Producto	Nivel de Producción	Unidad de medida producción	% Destinado a comercialización	% Destinado a autoconsumo	Rendimiento ¿Cuánta producción por unidad de área?	Unidad de medida rendimiento
2020	Ganado bovino	20	cabezas	20%	80%	5	cabezas/ hectárea
2021	Ganado bovino	30	cabezas	50%	50%	10	Cabezas por hectáreas
2022							
2023							
2024							
2025							

Año	Producto	Nivel de Producción	Unidad de medida producción	% Destinado a comercialización	% Destinado a autoconsumo	Rendimiento ¿Cuánta producción por unidad de área?	Unidad de medida rendimiento
2020	Yuca	50	kilogramos	75%	25%	10	kilogramos/ hectárea
2021							
2022							
2023							
2024							
2025							

4. (CUALI- V3) ¿Qué tipo de ganadería tiene? ☐ Cría ☐ Ceba ☐ Leche

5. (VMD-V1) Para el caso de la ganadería bovina, ¿con qué frecuencia se cambia el ganado de potrero (rotación interna)?

6. (VMD-V1) En promedio, ¿cuánto tiempo permanece el ganado desde su ingreso (para cría o engorde o leche) hasta su venta para sacrificio?

7. (CUALI- V4) En los últimos 5 años, ¿ha aumentado, disminuido o permanecido igual la cantidad de animales que se pueden mantener/alimentarse (*capacidad de carga*) en el área del proyecto ARR?

8. (CUALI- V5) ¿Qué medida tomó para manejar los animales en la(s) propiedad(es) que incluyó en el proyecto ARR? Rellene el siguiente cuadro, según corresponda:

(1) Opción	**(2) Sí/No**	**(3) ¿Cuál es el área total de esa otra finca?**	**(4) ¿Tiene esta otra finca capacidad para ser área de mitigación del proyecto ARR? Sí/No**	**(5) ¿Cuántas cabezas de ganado máximo se pueden tener en esa otra finca?**	**(6) VDM- V12 ¿Qué porcentaje de esa otra finca se puede considerar área de mitigación del proyecto ARR?**
Trasladarlos a otra finca propia		Expresar en hectáreas.		Expresar en número de cabezas	% del total respecto al área total de la finca especificado en la columna 2 de este cuadro.
Alquilar una finca para continuar con la actividad ganadera		Expresar en hectáreas.		Expresar en número de cabezas	% del total respecto al área total de la finca especificado en la columna 2 de este cuadro.
Vender los animales por falta de tierra o recursos para alquilar		No aplica	No aplica	No aplica	No aplica
Ampliar la finca (Si la amplía, preguntar cómo la amplió)		¿Cuánto la amplió? Expresar en hectáreas.	¿Tiene esta ampliación de finca capacidad para ser área de mitigación del proyecto ARR?	¿Cuántas cabezas de ganado se pueden tener en esa ampliación de finca?	% del total respecto al área total de la ampliación de la finca especificado en la columna 2 de este cuadro.
Otra, ¿cuál?					

Esta sección consulta preguntas para el área de mitigación de fugas del proyecto ARR:

9. (CUALI- V6) Especifique PARA EL CASO ANTES Y DESPUÉS DEL PROYECTO, ¿qué área y/o porcentaje del área de mitigación de fugas del proyecto estaba dedicada a?:

Antes del proyecto ARR		**Después del proyecto ARR**	
Uso	**% o Ha**	**Uso**	**% o Ha**
Descanso		Descanso	
Bosques nativos		Bosques nativos	
Cultivos		Cultivos	
Habitacional/ Vivienda		Habitacional/ Vivienda	
Pastoreo		Pastoreo	
Otros usos		Otros usos	
¿Cuáles otros usos?		¿Cuáles otros usos?	

10. (VMD- V3, VDM- V7) En el siguiente cuadro especifique la producción y el rendimiento de los productos y/o servicios que se han generado en las áreas de mitigación de fugas del proyecto entre 2020 y 2025. *Replique el cuadro para cada producto*.

Año	**Producto**	**Nivel de Producción**	**Unidad de medida producción**	**% Destinado a comercialización**	**% Destinado a autoconsumo**	**Rendimiento ¿Cuánta producción por unidad de área?**	**Unidad de medida rendimiento**
2020	Ganado bovino	20	cabezas	20%	80%	5	cabezas/ hectárea
2021							
2022							
2023							
2024							
2025							

11. (CUALI- V7) En los últimos 5 años, ¿ha aumentado, disminuido o permanecido igual la cantidad de animales que se pueden mantener/alimentarse (*capacidad de carga*) en el área de mitigación de fugas del proyecto ARR?

II. INFORMACIÓN CUALITATIVA

12. (CUALI- V8) ¿Cuántas personas componen su hogar?
    # Personas pueden trabajar_____
    # Personas que no pueden trabajar (Niños muy pequeños/Adultos mayores/Discapacitados) ______

13. (CUALI- V9) De las personas que trabajan, ¿cuántas trabajan en la finca que hace parte del proyecto ARR?

14. (CUALI- V10) ¿Qué porcentaje del **ingreso MENSUAL del hogar** proviene de la finca que hace parte del proyecto ARR?

15. (CUALI- V11) Además del trabajo de la finca del proyecto ARR, ¿qué otras actividades económicas realizan en el hogar para obtener ingresos?

16. (CUALI- V12) ¿A qué se dedicará el hogar ahora que no puede utilizar las tierras del área del proyecto ARR para ganadería?

17. (CUALI- V13) ¿Cuáles otros ingresos, diferentes a los de las actividades económicas, tiene el hogar? (*Por ejemplo, subsidios, pagos por servicios ambientales, remesas, arriendos de casa, etc*.)

18. (CUALI- V14) ¿Cuál es el mayor problema con la gestión de la finca que está en el **proyecto ARR**? *Gestión se refiere a temas como falta de mano de obra, retos con préstamos bancarios, cubrir gastos sanitarios por ejemplo de vacunación del ganado, etc.*

19. (CUALI- V15) ¿Cuál es el mayor problema con la gestión de la finca que está en el **área de mitigación de fugas del proyecto ARR**? *Gestión se refiere a temas como falta de mano de obra, retos con préstamos bancarios, cubrir gastos sanitarios por ejemplo de vacunación del ganado, etc.*

20. (CUALI- V16) ¿Estaría interesado en recibir capacitación sobre las mejores prácticas de las fincas? Si es así, ¿en qué formato funcionará para usted? ¿Qué distancia podría recorrer para recibir esta capacitación?

21. (CUALI- V17) Qué condiciones deberían cumplirse para que usted continúe participando en un programa agropecuario que promueva la conservación del medio ambiente? *Por ejemplo, se pueden recibir respuestas como: es fundamental que mi ingreso no se vea afectado negativamente; si las prácticas de conservación reducen mi productividad, debería haber incentivos; debe haber espacios donde podamos tomar decisiones y aportar ideas; Necesito certeza sobre el acceso y uso de mis tierras a largo plazo; quiero ver resultados concretos de las acciones de conservación.*

22. (CUALI- V18) ¿Qué factores lo motivarían a continuar por más tiempo en el proyecto ARR? *Por ejemplo, se pueden recibir respuestas como: recibir beneficios económicos por la captura de carbono sería un incentivo importante; si se reconoce y paga mejor mi producción sostenible, Créditos o apoyo financiero con tasas preferenciales serían*

clave; me motivaría recibir formación y apoyo continuo para mejorar mis prácticas; bonificaciones o pagos adicionales por conservar el medio ambiente serían atractivos; poder vender mis productos en mercados que valoran la sostenibilidad me motiva; el prestigio de participar y obtener certificaciones me incentivaría.