OPEN ACCESS
Advances in Animal and Veterinary Sciences

Research Article

Sustainable Agropolitan Development Via Laying Hen Farming: A System Dynamics Model for Lima Puluh Kota Regency, Indonesia

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Abstract | Many countries adopt agropolitan development to promote equitable growth, ensure food security, and strengthen rural economies. This study focuses on Limapuluh Kota Regency (LKR), West Sumatra, aiming to support sustainable agropolitan development through a systems-based analysis of chicken egg production. A system dynamics approach is applied, modeling two primary subsystems: the layer hen population and business profitability. These subsystems consist of interacting variables that evolve over time. Secondary time-series data from 2016–2020 were obtained from the Ministry of Agriculture, the Central Statistics Agency, and related sources. Simulation results indicate that the developed model adequately represents the real dynamics of egg production in LKR. The model serves as a tool to guide policy decisions for enhancing productivity and sustainability. Three policy scenarios—moderate, optimistic, and pessimistic—were evaluated. The moderate scenario, with no change in system components, leads to a 26% annual increase in production but only a 1% rise in profit per farmer. In the optimistic scenario, a 6.88% annual increase in egg prices boosts production by 15% and profits by 2% annually. The pessimistic scenario, involving a 60% annual rise in feed costs, results in a 32% cost increase, a 25% production decline, and a 16% decrease in profits per farmer each year. These findings underline the importance of proactive policy planning and investment in sustainable practices. The model provides a strategic foundation for improving egg production and achieving long-term resilience in agropolitan development.

Keywords | Sustainable development, Agropolitan, Modeling, Policy directions, Laying hen, Dynamic systems

Received | May 23, 2025; **Accepted** | June 20, 2025; **Published** | July 31, 2025
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Citation | Yuzaria D, Fitrimawati, Rias MI (2025). Sustainable agropolitan development via laying hen farming: A system dynamics model for lima puluh kota regency, Indonesia. Adv. Anim. Vet. Sci. 13(8): 1801-1815.
DOI | https://dx.doi.org/10.17582/journal.aavs/2025/13.8.1801.1815
ISSN (Online) | 2307-8316; **ISSN (Print)** | 2309-3331

INTRODUCTION

One of the primary objectives within the UN-backed Sustainable Development Goals (SDGs) is to eliminate hunger from people's lives. Enhancing food production from animal protein sources involves establishing agropolitan regions. The primary aim of agropolitan regions is to accelerate rural development by focusing on agricultural and agribusiness activities. Agropolitan development provides an approach for supporting rural economies in accordance with the Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger). Egg production, as a vital component of agropolitan agriculture, contributes significantly to food security by boosting the supply of low-cost, high-quality animal protein in rural communities.

This approach seeks to improve the welfare and prosperity of rural communities, particularly farmers, by increasing agricultural productivity and incomes. Laying hen farming is a common and economically viable agricultural activity across various countries, including Indonesia, and contributes substantially to advancing the SDGs (Bakrie *et al*., 2021; Dal Bosco *et al*., 2021). As well as having an impact on agriculture and the use of land development to improve environmental services for the community (Kaleem and Shabir, 2023; Fischer and Eastwood, 2016). The implementation of the agropolitan project illustrates the government's committed endeavors to eradicate poverty and promote rural development (Ismail *et al*., 2025).

Sustainable agriculture faces significant challenges such as global climate change, depletion of natural resources, and meeting increasing human needs. To overcome this challenge, efforts are needed through government policies and more sustainable agriculture practices (Ricart *et al*., 2023). The growing and widespread effects of climate change across various sectors and regions have driven the advancement of integrated and adaptive strategies designed to provide more effective and sustainable solutions (Hidalgo *et al*., 2021). In many developing countries, regional development often leans towards excessive exploitation of natural resources, neglecting environmental safety (Surya *et al*., 2020).

Therefore, it is crucial to establish agropolitan areas, ensuring the preservation of social, cultural, and political harmony for both current and future generations (Fatkhiati *et al*., 2015). The agropolitan model, also referred to as the Cluster Regional Model, advocates for economic activities rooted in local resources, fostering the growth of secondary economies within the project area (Ismail *et al*., 2020). The development of agropolitan regions centered on layer poultry farming has the potential to support decentralized development and stimulate local economic growth by enhancing community empowerment through the optimal use of locally available resources (Latif *et al*., 2022; Surya *et al*., 2020; Tedeschi *et al*., 2015).

Lima Puluh Kota Regency (LKR) in West Sumatra holds considerable potential for advancing the layer poultry farming subsector, primarily due to the strong demand in the egg market. This is evidenced by the volume of broiler eggs exported from the area each week. Second, the development of animal enterprises is greatly aided by the readily available land potential and feed sources. Thirdly, this area's culture favors the growth of laying hens in terms of labor and the community. Fourth, the agro-climatic conditions are adequate. Fifth, there is fair local government support for the laying hens business. Given this substantial potential, promoting agropolitan development centered on laying hens farming represents an appropriate strategy for achieving balanced rural–urban integration, tailored to the specific potential and characteristics of the region (Pinheiro and Govind, 2020; Wei *et al*., 2021).

Agropolitan cities maintain harmony in social, cultural, and political settings without compromising present or future generations. Sustainability is commonly understood as the fulfillment of current needs while preserving the capacity of future generations to meet their own requirements. (Surya *et al*., 2020).

The agropolitan development program in LKR, West Sumatra, was officially initiated through the Regent of Lima Puluh Kota's Decree No. 398/BLK/2005, dated June 6, 2005. This decree designated the districts of Payakumbuh, Mungka, and Guguak as agropolitan zones with a specific focus on laying hen agribusiness. In its initial stages, the implementation of this policy yielded positive economic outcomes for layer poultry farmers in the region. According to Soares *et al*. (2022), laying hen farming is a sub-sector of agriculture that can significantly impact economic stability and inflation in a given country. Farmers exhibit a greater preference for laying hen farming over broiler chicken business due to the heightened demand for eggs (Rondoni *et al*., 2020).

Nevertheless, governmental policies do not always achieve the intended outcomes, and instances of policy failure are common in public governance (Mueller, 2020). Even well-intentioned policies based on sound economic principles may fail if the implementation process is not adequately addressed. There are numerous reasons for policy failure, and governments often face difficult decisions about which measures to adopt. These include determining when to impose or ease restrictions, allocating funds, identifying revenue sources, and prioritizing national concerns over international cooperation (Frieden, 2020). Inadequate financial and human resources can also hinder policy implementation, including insufficient funding and a shortage of trained personnel (Masud and Khan, 2023). The sustainability of the laying hen farming sector in LKR remains below expectations across several critical dimensions. A range of factors contributes to the decline in production, particularly in relation to the implementation of government policies (Bhanja and Pragya, 2018; Edwards and Hemsworth, 2021). The development of this sector within the agropolitan framework is hindered by inadequate infrastructure and facilities, limited access to financial capital, and a shortage of skilled human resources. Current production levels are insufficient to meet the demand from surrounding regions such as Riau, Jambi, Bengkulu, and Jakarta. Furthermore, poor infrastructure and high transportation costs continue to limit the efficient distribution of eggs and chickens to these markets (Kidd and Anderson, 2019).

Governmental commitment in Lima Puluh Kota Regency (LKR) toward the development of sustainable agropolitan areas for layer poultry farming remains limited and insufficiently structured. The marketing sector struggles to process raw materials within the agro-industrial subsystem due to a shortage of skilled human resources. Additionally, the implementation of agropolitan policy is hindered by inconsistent laws and institutional practices. One potential solution to these challenges is the adoption of the agropolitan area concept—a development approach that integrates environmental, economic, and community interests. Developing agropolitan areas with integrated laying hen farms can be an effective strategy to enhance the social and economic well-being of local communities. This study aims to develop a model of the chicken egg production system in Lima Puluh Kota Regency and to propose alternative policy recommendations that promote sustainable agropolitan development by enhancing egg production.

Research Method

This study employs a system dynamics approach to develop policy strategies aimed at fostering the sustainable growth of agropolitan areas, with a particular emphasis on integrated layer poultry farming in Lima Puluh Kota Regency, West Sumatra, Indonesia. The analysis utilizes PowerSim Constructor Version 2.5, a simulation software designed for strategic planning and policy evaluation. This methodology allows for the examination of dynamic and complex interrelationships within the production system, as well as the evaluation of potential policy impacts. The study draws on secondary time-series data from 2016 to 2020, sourced from the Ministry of Agriculture, the Central Statistics Agency, and other credible institutions. The study relied on secondary data from government sources, which may have biases such as underreporting, outdated information, or political interference. These limitations can impact the accuracy and reliability of the analysis (Baldwin *et al.*, 2022; Fernández-Ardèvol and Rosales, 2022).

The dynamic systems approach in policy research enables a comprehensive understanding of policy evolution over time by capturing intricate variable interactions, modelling system behaviour, assessing environmental responsiveness, analyzing trends, and evaluating long-term policy implications. As highlighted by Selin *et al.* (2023), this method provides a solid and integrative framework for designing and evaluating policies that are both effective and sustainable. In the context of this research, dynamic modelling is applied to examine policy shifts and simulate alternative scenarios to support the future development of agropolitan regions in Lima Puluh Kota Regency.

Analysis Method

The model was developed using a systems dynamics framework aligned with the study's objectives. This methodology is well-suited for simulating and analyzing complex systems, as it effectively captures dynamic behaviors, feedback loops, time delays, and other system processes through quantification and control. As such, system dynamics offers significant advantages in understanding, enhancing, and managing systems with prolonged development cycles and intricate feedback structures (Ramadhan *et al.*, 2024; Antón and Sauer, 2021; Boussios *et al.*, 2022). The system dynamics method involves several stages (Barbrook and Penn, 2022).

Needs analysis – identifying the requirements and interests of system actors (stakeholders): Needs analysis is the initial stage of a system assessment that identifies the needs of system actors (*stakeholders*). Each stakeholder possesses distinct needs that influence the overall performance of the system. These stakeholders anticipate that their respective interests will be accommodated. At this phase, mapping the requirements of every stakeholder forms the essential basis for grasping the system's dynamics.

Problem formulation: Defining interrelated problems faced by stakeholders based on the needs analysis. Based on the analysis of needs, it will be seen that needs are in line (synergistic) and needs that are not in line (contradictory). The needs of contradictory actors require solutions.

System identification: It aims to recognize the relationship between the "statement of needs" and the "statement of problems" that must be resolved to meet those needs. At this stage, one of the approaches used is to compile an *input-output* diagram (Figure 2) and a causal *loop* (Figure 3).

Modeling and simulation: Creating a dynamic model to analyze the system using simulations (Makmun *et al.*, 2024). The modeling procedure is to restate the problems to be solved under the objectives of the system study, formulate models, test, and analyze models.

A Dynamic Modeling Approach to Egg Production in Lima Puluh Kota Regency

Modeling integrated layer poultry farming using dynamic simulation aims to assess future development policies as a driving force for agropolitan areas and to evaluate their impacts on both the economy and the environment. After the parameters to be simulated are identified, the variables that affect each parameter will be known. Furthermore, a model was designed with a cause-and-effect diagram of the variables of each parameter of chicken egg production in the LKR. Variables for dynamic simulation in this study include layer chicken population, expected production rate, chicken demand, labor, egg production, total business costs, business revenues, and business profits. The following key steps are typically undertaken to conduct dynamic analysis for modeling a laying hen farming business: Define the system boundaries and objective by identifying the key components of the laying hen farm to be modelled, e.g, hens, feed, environment, and production, set the goal. Identify key variables and relationships and map how these variables interact dynamically. Simulate the model over time and analyze results.

Model Development

Model development follows the system dynamics stages. The egg production problem in LKR is complex, involving multiple interrelated variables. Setting clear goals and boundaries helps define the problem's scope. A needs analysis is conducted to understand the different yet interrelated requirements of system actors (Makmun *et al*., 2024). Based on this, a mental model is constructed using a causal loop diagram, indicating relationships with (+) for positive and (−) for negative influence.

Following the causal loop diagram, a stock-and-flow diagram is developed using PowerSim software. This includes:

- Formulation of equations based on historical data to reflect real-world problems.
- Verification by comparing simulation outputs with expected system behavior.
- Simulations are then run for the 2016–2026 time horizon. Several scenarios are tested to observe behavioral changes and forecast the egg production potential in LKR.

Model Validation

Model validation refers to the process of determining the extent to which a conceptual model accurately represents the real-world system it seeks to emulate. This includes evaluating whether the simulated model's behavior consistently aligns with the observed dynamics of the actual system (Antonelli *et al*., 2018; Piedrahita *et al*., 2025). Model validation involves assessing the model's performance by comparing its behavior to that of the actual system. One commonly employed method for validating models is the Mean Absolute Percentage Error (MAPE), a quantitative indicator used to assess the percentage deviation between simulated outcomes and actual observed data. The MAPE value represents a relative error metric (expressed as a percentage of the actual value) that uses the absolute value of each error to prevent the cancellation of positive and negative deviations (Azaria, 2023; Tofallis, 2021; Badiru, 2023). The MAPE is calculated using the following formula:

$$MAPE = \frac{1}{n}\frac{|X_m - X_d|}{X_d} \times 100\%$$

Where;
Xm is the simulated (modeled) value,
Xd is the actual (observed) data,
n is the number of data points (periods).
The accuracy of the model using the MAPE test can be categorized as follows (Bazilah *et al*., 2016; Joanna *et al*., 2024):

- MAPE < 5%: Very accurate
- 5% ≤ MAPE < 10%: Accurate
- MAPE ≥ 10%: Inaccurate

According to Bazilah *et al*. (2016), the MAPE value of <5% is considered 'very accurate.' Meanwhile, according to the criteria of Vexpower (Taylor, 2022) and SAP Community (2021), estimates with MAPE of less than 5% are considered acceptable accuracy.

Modeling and Simulation (MandS)

Modeling is a widely accepted scientific method used to analyze systems and predict their behavior before physical implementation. In both scientific computing and realistic animation, simulation, defined as the step-by-step computation of a system's complete behavior over time, is considered one of the most important and commonly used analytical techniques (Samudra *et al*., 2021).

Table 1: Types, data sources, and analysis methods of the development model of agropolitan area based on layer farming in LKR.

Specific Objectives	Data Type	Data Form	Data Source	Method Analysis	Expected Output
Modeling egg production in the Agropolitan area in LKR	Secondary	Time series data from 2016 to 2020	Relevant offices or agencies. Expert opinion	System Dynamics with Powersim	The model in the form of state, optimistic, and pessimistic scenarios
Provide alternative policies to support the production of chicken eggs	Secondary	Time series data from 2016 to 2020	Relevant offices or agencies. Expert opinion	System Dynamics with Powersim	Alternative policies to support the production of chicken eggs

Source: Designed according to research objectives.

The data sources and variables used in the research process are detailed in Table 1. The mathematical equation of the dynamic model of chicken egg production is:

Laying hens populations=Production−Depletion

Depletion=Culling+Chicken Death Rate

Production=Workforce ×Productivity

Workforce=Recruitment−Attrition

$$Recruitment = \frac{(Desired\ Workforce - Workforce)}{Time\ to\ Adjust\ Workforce} + Attrition$$

$$Desired\ Workforce = \left(\frac{Desired\ Production\ Rate}{Productivity}\right) + Profit\ Effect$$

$$Desired\ Production\ Rate = Culling\ Demand + \frac{(DOC - Laying\ Hens\ Population)}{Maintenance\ Time}$$

$$DOC\ (Day\ Old\ Chicks) = Culling\ Demand \times DOC\ Supply\ Time$$

$$Culling\ Demand = Culling + Change\ in\ Demand$$

$$Culling = Laying\ Hens\ Populations \times Culling\ Fraction$$

$$Change\ in\ Demand = \frac{(Culling - Culling\ Demand)}{Time\ to\ Change\ Demand}$$

$$Egg\ Production = Laying\ Hens\ Population \times Laying\ Hens\ Productivity$$

$$Profit = Revenue - Total\ Cost$$

$$Revenue = Egg\ Revenue + Culling\ Revenue$$

$$Total\ Cost = Feed\ Cost + Operational\ Cost + Other\ Cost$$

RESULTS AND DISCUSSION

Overview of The Laying Hen Industry in Agropolitan Areas in LKR

The research was carried out in Lima Puluh Kota Regency (LKR), which was formally designated as an agropolitan area through Regent Decree No. 398/BLK/2005. The designated area includes Mungka, Payakumbuh, and Guguak Districts. The region is characterized primarily by flat and lowland topography, with limited areas of hilly terrain. Climatic conditions range from 24.7°C to 27.9°C, and the average annual rainfall is approximately 313.25 cm, classifying it as an area with high rainfall according to Livestock and Animal Health Statistics (2020). As indicated by Paura *et al*. (2022), such climatic conditions are conducive to laying hen farms, as laying hens thrive in a comfortable and stable climate for optimal egg production. Laying hens require stable temperatures increase , typically ranging between 15°C and 24°C (59°F and 75°F) for peak performance. Extreme temperatures, whether excessively hot or cold, can disrupt egg production. The ideal temperature range (thermoneutral zone) for laying hens to achieve optimal performance is between 19 and 22 °C (Chang *et al*., 2018; Pontara *et al*., 2020). Overall, egg production is influenced by various environmental, construction, and human factors.

Table 2 presents a summary of the dynamics of chicken egg production in LKR, as indicated by the average trends in layer chicken population, egg production, egg prices, local consumption, and interregional distribution from 2016 to 2020.

Table 2: Compound annual growth rate (CAGR) of layer chicken population, egg production, egg prices, local consumption, and shipments outside the region (2016–2020) (percent per year).

Variable	CAGR (%/year)
Layer Chicken Population	11.69
Egg Production	11.81
Egg Price	1.40
Local Consumption of Eggs	10.29
Selling Eggs Outside the Region	13.55

Source: To Livestock and Animal Health Statistics (2020), Limapuluh Kota Regency in Figures. Note: CAGR (Compound Annual Growth Rate) is used to represent the average annual growth rate of each variable over the period 2016–2020, accounting for the cumulative effect of year-on-year growth.

Based on Table 2, the layer chicken population in the LKR increased at a considerable compound annual growth rate (CAGR) of 11.69%, with slightly higher growth in egg production at 11.81% each year. This close match shows that increases in layer population directly contributed to an increase in egg output, indicating a consistent expansion of poultry farming capacity. Despite an upward trend in output, egg prices increased by just 1.40% each year, indicating that supply expansion may have outpaced demand, placing downward pressure on market prices. Nonetheless, local egg consumption increased by 10.29% each year, demonstrating a positive shift in consumer behavior toward higher animal protein intake, most likely due to increased public awareness of nutrition and economic benefits. Furthermore, egg shipments outside the region expanded at the highest rate, 13.55% annually, suggesting that external markets played a crucial role in absorbing surplus production. This interregional trade appears to be a vital mechanism for stabilizing local prices and sustaining profitability for egg producers.

Layer chickens refer to hens reared specifically for egg production, typically maintained over a 55-week laying cycle. In Lima Puluh Kota Regency (LKR), the population of layer chickens demonstrated an upward trend during the period from 2016 to 2020. In 2016, the layer chicken population stood at 4,978,625 birds, and by 2020, this figure had surged to 7,748,600 birds (LKR to Livestock and Animal Health Statistics (2020). This growth in the layer population was accompanied by a corresponding increase in both local egg production and consumption, as depicted in Figure 1.

In 2016, layer egg production amounted to 38,223,751 kg or 737,221 kg per week, with local consumption of layer eggs reaching 20,803,964 kg. By 2020, these figures have increased to 59,741,706 kg for egg production and 30,784,271 kg for egg consumption. Between 2016 and 2020, LKR experienced an excess layer egg production of 13.55 percent per year from 17,419,787 kg to 28,957,435 kg. This increase occurs because the implementation of new policies is carried out in LKR. At that time, a laying hen farming business sprang up with assistance facilities from the government in the form of developing agropolitan areas. However, there has been to decline in the last 3 years due to various obstacles such as an increase in feed prices, weak government supervision.

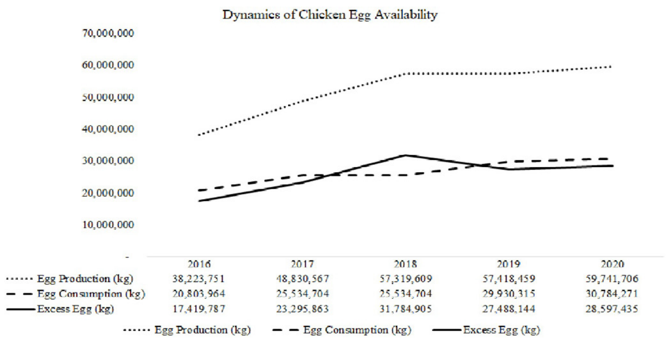


Figure 1: Dynamics of chicken egg availability in LKR for the 2016-2020 period.

Modeling The Chicken Egg Production System In LKR

Based on the system dynamics modeling stage, the following results were found:

Needs analysis: Needs analysis serves as the preliminary phase in system evaluation, aimed at identifying the specific requirements of system stakeholders. These actors possess varying needs, each of which has a distinct influence on overall system performance. The systems approach is used in solving complex problems and involving various interested parties (Costa *et al*., 2019; Lehtinen *et al*., 2019; Rebs *et al*., 2019). System actors expect these needs to be implemented. Through a review of relevant literature, several key stakeholders involved in layer egg production and their respective needs have been identified. The selection of these actors and the formulation of their needs have been adapted to align with the scope and limitations of the study. At this stage, stakeholder needs are recognized as a foundational element in understanding system behavior. A detailed overview of each actor's needs is provided in Table 3.

Table 3 shows the assessment of stakeholder-based requirements on the needs analysis. While the initial comments focused on profits and production growth, further discussions emphasized the need to address systemic risks such as disease outbreaks, input price volatility, and market access. The combination of these elements can reflect the operational realities and expectations of each actor in the egg production process.

Table 3: Identified system actors and their needs.

Actors	Needs
Farmers	Increased profits with risk mitigation (e.g., disease, input prices)
Government	The availability of eggs and chicken meat that adequately fulfill the community's needs
Livestock Industry	Production continuity and large profit margins
Society	The need for eggs and chicken meat is met

Source: Research data.

Problem Formulation

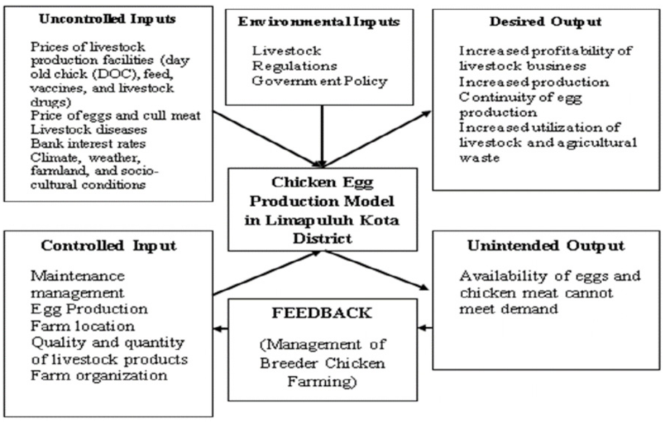
This is necessary to integrate the needs of actors. In general, solutions are obtained from understanding the mechanisms that occur in the system. Based on this mechanism, the relationship between factors can be known so that solutions can be determined based on the knowledge of interfactor relationships. Understanding the system mechanism is carried out at the system identification stage. Drawing from the identified challenges within the development framework of the layer chicken farming system in Lima Puluh Kota Regency, the following key issues have been outlined:

- Limited ability to manage livestock maintenance, resulting in low production and product quality, high livestock mortality rate, and others.
- The development of the layer chicken farming system in Lima Puluh Kota Regency faces significant constraints due to inadequate facilities and infrastructure, limited access to capital, and a shortage of skilled human resources.
- The limited commitment and accountability of the local government hinder the effective development of the layer chicken farming system in Lima Puluh Kota Regency.
- Laws and institutions that are less consistent in their application.

System identification: System identification is intended to offer a thorough understanding of the interrelationships among key factors that shape the dynamics of the layer poultry farming system in Lima Puluh Kota Regency (LKR).

These interrelationships are illustrated in the input-output diagram (Figure 2), which maps the system components into five key categories: inputs (controlled and uncontrolled), environmental inputs, outputs (desired and unintended), and feedback mechanisms. Uncontrolled inputs include external factors that cannot be managed directly by farmers, such as fluctuations in the prices of livestock production facilities (e.g., day-old chicks, feed, vaccines, and drugs), egg and cull meat prices, disease outbreaks, bank interest rates, as well as climatic, weather-related, farmland,

and socio-cultural conditions. These variables significantly affect the stability and predictability of the production process. Conversely, controlled inputs denote variables that can be regulated internally, including management practices, production efficiency, farm location, the quality and volume of poultry products, as well as the organizational structure of the farming operation. Effective control and optimization of these variables are essential for improving productivity and profitability. Environmental inputs consist of broader institutional and regulatory factors, such as livestock laws, government policies, and industry regulations, which shape the operational landscape and influence farm-level decision-making. Desired outputs represent the objectives of the system, including increased profitability of the livestock business, higher and more consistent egg production, and better utilization of agricultural and livestock waste. Achieving these goals supports the sustainable development of agropolitan areas. Conversely, unintended outputs reflect system inefficiencies, such as the inability of egg and chicken meat availability to meet consumer demand, highlighting mismatches in supply and demand or inefficiencies in production and distribution. Lastly, the feedback loop, centred on the management of breeder chicken farming, is pivotal in guiding system regulation through continuous learning and adaptive modifications over time. Feedback mechanisms help improve decision-making and enhance system performance through continual refinement based on observed outcomes.

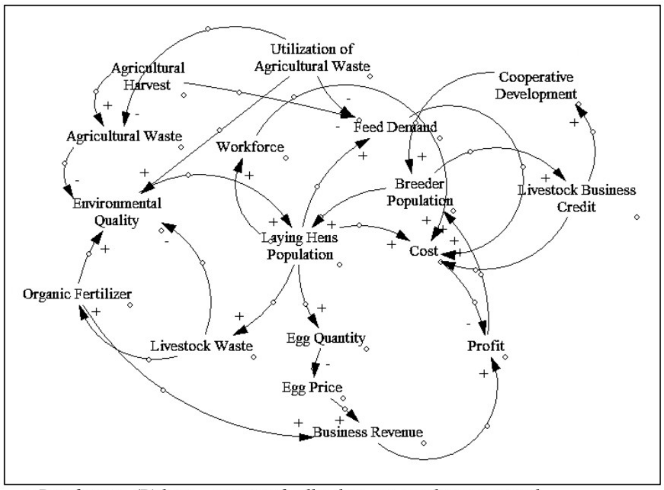


Legend:
Rectangles: Inputs, outputs, and model components
Solid arrows: Influence or directional relationship

Figure 2: Input output diagram of the dynamical system of chicken egg production in limapuluh kota regency.

System Conceptualization

The challenge of chicken egg production in LKR represents a relatively intricate systemic issue encompassing diverse variable components that interact and are integrated. Chicken egg production is conceptualized as a dynamic systems problem, characterized by temporal variations and influenced by multiple interrelated factors. The structural framework of the egg production system in Lima Puluh Kota Regency is illustrated through the Causal Loop Diagram of the layer poultry farming system, as depicted in Figure 3.



\+ : *Reinforcing (R) loop – positive feedback in egg production growth.*
\- : *Balancingm (B) loop – negative feedback regulating feed costs.*

Figure 3: Causal loop diagram (CLD).

Figure 3 illustrates the causal loop diagram (CLD) that captures the dynamic interrelations within the laying hen farming system in Lima Puluh Kota Regency. This diagram provides a systems-based view of how key variables influence each other through feedback loops—both reinforcing (positive) and balancing (negative)—that drive system behavior over time. At the core of the system is the laying hen population, which directly influences egg quantity, and subsequently, egg price and business revenue. Higher business revenue improves profitability, which can encourage cooperative development and access to livestock business credit, enabling farmers to expand the breeder population and further grow the laying hen population—a reinforcing feedback loop. A dynamic systems analysis conducted by Aboah and Enahoro (2022) likewise revealed that fluctuations in egg prices exert a significant and prolonged impact on the dynamics of egg production. When production increases and leads to an oversupply, egg prices tend to fall, so farmers' income decreases. This is a classic example of balancing feedback in the poultry farming economic system. According to Pavlova and Lukanov (2020), participation in layer poultry farming is influenced by the enterprise's profitability and the accessibility of business incentives provided through farmer–livestock cooperatives.

The model also shows how the breeder population increases feed demand, which may place pressure on the utilization of agricultural waste. This highlights a cross-sectoral interaction between agriculture and livestock. Increased use of agricultural waste contributes to livestock waste, which, when properly managed, produces organic fertilizer, enhancing environmental quality and improving agricultural harvests. This forms a positive loop supporting agricultural-livestock integration. Omomule *et al*. (2020) emphasize that environmental quality indicators are influenced by the management practices of agricultural and livestock waste, particularly through their conversion into organic fertilizers and other by-products. The conversion of waste into organic fertilizer can be sold to bolster business revenue, and utilizing agricultural waste for animal feed can curtail feed costs.

Conversely, the system also contains balancing loops. For example, while an increase in the laying hen population leads to greater production, it also increases operational costs (feed, labor, etc.), which may reduce profits if not managed effectively. Increasing production rates require increasing breeding capacity, but it also puts pressure on costs and market prices, thus ultimately balancing the rate of production growth (Aminuddin and Liane, 2023). Moreover, an oversupply of eggs may decrease egg prices, reducing business revenues—a classic balancing feedback loop. The workforce plays a key role in sustaining production efficiency and managing system complexity. As environmental quality improves through waste management and circular resource flows, it creates a more sustainable farming system. This CLD serves as the foundation for developing stock-and-flow diagrams and conducting dynamic simulations. It helps identify leverage points in the system where policy interventions can produce meaningful and sustainable improvements in both economic and environmental outcomes.

Modeling and Simulation

Modeling in this study entails converting the identified problem into a mathematical framework that accurately represents the real-world system. This process links the variables outlined in the conceptual model. Several key assumptions form the basis of the modeling approach: the total layer chicken population in 2016 was recorded at 95,743 birds per week (Central Bureau of Statistics, 2016). The dynamics of population growth are presumed to be shaped by inflows, represented by production-related variables, and outflows, represented by depletion factors. The inflow rate is influenced by labour availability and labour productivity in rearing day-old chicks (DOC) until they reach laying age at 16 weeks. It is assumed that each worker has a productivity rate of 1,500 birds per person per week, indicating their capacity to rear 1,500 DOC weekly. Meanwhile, the outflow rate is determined by mortality during rearing and the culling of layers that have completed their productive cycle. Mortality during rearing is estimated at 5% of the population, while the culling rate is assumed to be 37% per week. The numerical values and assumptions assigned to each variable are derived from Lima Puluh Kota Regency's statistical data for 2016–2020.

In this model, it is assumed that the feed consumed by layer chickens consists of a formulation comprising 45% concentrate, 15% rice bran, and 40% maize, based on total feed requirements. The availability of concentrate feed is presumed to be constant, as it is supplied directly by commercial feed mills. In contrast, the supply of rice bran and maize is assumed to originate from local agricultural production within Lima Puluh Kota Regency. The values for the rice bran and maize harvest fraction variables are the average harvest values of rice and maize crops in LKR in the 2016-2020 timeframe. Livestock waste in this model is assumed to be used only for manure, where the value is assumed to be 0.23 kg/head/week.

The variable representing demand for culled chickens reflects the market demand for meat from culled layers, which is influenced by the interaction between the culling rate and the temporal fluctuations in demand. This demand variable subsequently impacts the quantity of day-old chicks (DOC) required to maintain production. Furthermore, the number of DOCs that can be reared into productive layer chickens is determined by the availability of labour and the labour's capacity to manage DOCs during the rearing phase.

The business revenue variable in the model is the sum of the egg revenue and culling revenue variables (Afandi *et al*., 2020; He *et al*., 2022). The egg revenue variable is a variable that describes the value of the sales of layer eggs, with the assumption that layer hens have the productivity of 0.77 kg/head/week, where the price of eggs is IDR 23,700/kg. The magnitude of the value in the variable productivity of laying hens and egg prices is obtained from the average value of these variables in the 2016-2020 range. The variable of rejected hens revenue is a variable that describes the amount of sales value of culled layer meat, with the assumption that the price of culled chicken is IDR 50,000/bird.

The total business cost variable represents the aggregate of feed costs, operational expenses, and other associated expenditures (Abadi *et al*., 2022; Afandi *et al*., 2020). Feed costs are directly determined by the volume of egg production, with an estimated cost of IDR 10,000 per kilogram of eggs, based on an assumed feed conversion ratio (FCR) of 2.30. Additionally, it is assumed that feed prices—particularly for concentrates—experience an annual increase of 30%, reflecting prevailing trends in price escalation. The operational cost variable includes all expenses associated with the production process borne by farmers, such as electricity, water, labor wages, equipment maintenance, raw materials, social contributions, healthcare and security services, fuel, and various other incidental costs. In the model, operational costs are valued at IDR 1,000 per kilogram of eggs. Meanwhile, the "other costs" category includes The cost of pullets is amortized over their expected laying period and included in the production cost calculation.(in this case is to account for the reduced number of pullets due to death, disability and health), housing investment depreciation, marketing, vaccines and medications, and additional incidental expenses, collectively valued at IDR 2,570 per kilogram of eggs in the simulation.

The business profit variable is the result of the operation of subtracting the business revenue variable from the total business cost variable. The profit generated from livestock farming is assumed to be allocated, in part, for the repayment of credit installments and also contributes to the revenue of the livestock cooperative.

The labor variable functions as a stock variable within the model, influenced by both inflows and outflows. Inflows are determined by the expected labor demand and the labor adjustment time, which is assumed to be 8 weeks—indicating that, on average, a worker requires an 8-week rest period before commencing work in poultry housing. Outflows are influenced by the labor turnover time, set at 104 weeks, meaning that a worker typically remains employed for approximately two years before exiting the job. Labor productivity is estimated at 1,500 chickens per person per week, implying that each worker is capable of managing 1,500 chickens.

The breeder variable represents individuals who own layer chickens and employ workers. It is assumed that breeders constitute 25% of the total labor force, as they also perform labor functions within their farming operations. The model further assumes that all layer poultry farmers are members of a livestock cooperative. Cooperative members are required to allocate 5% of their business profits to support cooperative development each time they realize a profit. All layer chicken farmers have business credit payment obligations to financial institutions. Credit installment payments are assumed to be 20% of business profits, assuming all farmers are disciplined in paying credit installments so as not to cause bad credit problems at financial institutions.

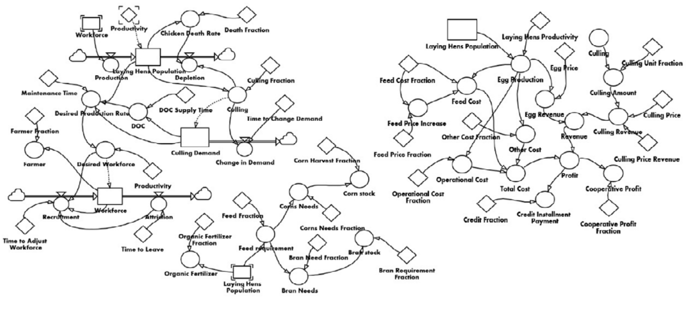


Figure 4: Stock flow diagram of chicken egg production model in limapuluh kota regency.

The model is done in Powersim software using stock flow diagrams. Complete arrow box diagram for chicken egg production model in LKR as illustrated by Figure 4.

Figure 4 illustrates, in the context of laying hens' egg production in agropolitan areas, that Stock-Flow Diagrams are used to represent stock and flow variables related to these aspects of production. Stock-Flow Diagram in the analysis of the dynamic system of egg production of laying hens in agropolitan areas represents stock (number of chickens and eggs) and flow (production, feeding, and sale of eggs) over time. These diagrams help visualize complex interactions between variables and understand the impact of changes in production systems. Its application helps stakeholders in more efficient planning and management.

Mathematical models in chicken egg production help forecast the behavior of the system, analyze the impact of changes, and optimize production. With this model, stakeholders can identify strategies to improve efficiency and manage risk. Data-driven decision making and policy scenarios can be improved. The model also supports risk management and helps design sustainable policies. With mathematical equations, egg production can be managed more efficiently and respond to changing conditions.

Based on the results of the model simulation, a solution is obtained to support decision-making so that this dynamic model simulation can be used as a tool to make guesses. According to Samudra *et al.* (2021), the advantages of using simulations include being able to provide answers if the analytical model used does not provide an optimal solution. Simulation models are more realistic than real systems because they require fewer assumptions. The results of the previous year's research indicated that laying hen farms in LKR, in terms of the ecological dimension, showed sustainability, the economic dimension was less sustainable, while for the socio-cultural dimension, infrastructure and institutions were quite sustainable.

To improve the sustainability status of the agropolitan area of laying hens in LKR, a progressive-optimistic scenario strategy is needed to make comprehensive improvements to all sensitive attributes. At least 7 attributes of key factors are generated in the prospective analysis, so that all sustainable dimensions for regional development based on laying hen farming can be realized Yuzaria *et al.* (2019).

Policy Direction for Sustainable Agropolitan Development Based on Laying Hen Farming

Modeling of the dynamic system of chicken egg production in LKR through design, simulation, and model analysis is carried out per the objectives and model scenarios. The main objective of the modelling is to distinguish the behavioral patterns of chicken egg production in LKR. Patterns of laying hen production behavior from the dynamic analysis results in various scenarios. The results of the simulation based on the assumption data are presented in Figure 5.

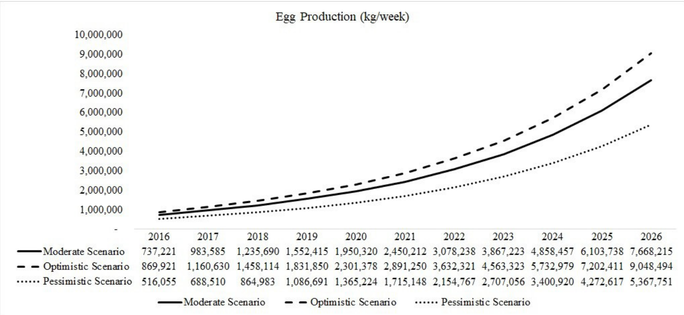


Figure 5: Chicken egg production under moderate, optimistic, and pessimistic scenarios.

Various scenarios employed for analyzing chicken egg production in LKR and their corresponding outcomes encompass.

Table 4: Simulation results of the business analysis of chicken eggs in the moderate scenario.

Year	Farmer (men)	Revenue (billion IDR)	Total Cost (billion IDR)	Profit (billion IDR)	Profit/Farmer (billion IDR)
2016	19.93	19.096	11.257	7.839	0.393
2017	24.23	25.477	15.019	10.458	0.432
2018	30.45	32.008	18.869	13.139	0.431
2019	38.25	40.216	23.705	16.506	0.432
2020	48.05	50.518	29.781	20.737	0.432
2021	60.37	63.467	37.415	26.052	0.433
2022	75.85	79.734	47.005	32.730	0.432
2023	95.29	100.171	59.053	41.119	0.431
2024	119.71	125.847	74.189	51.658	0.432
2025	150.39	158.103	93.204	64.899	0.432
2026	188.94	198.627	117.094	81.533	0.432

Source: Research data processed.

Scenario Without Component Change (Moderate)

Under the baseline scenario—where no changes are made to system components—the model operates in accordance with the initial assumptions and reflects current conditions. As shown in Table 4, simulation results indicate that the growth rates of the layer chicken population, egg production, and demand for culled chickens reach approximately 26% per year. Meanwhile, labor requirements increase by 25% annually. Additionally, business revenue, total operational costs, and net operating profits all exhibit an annual growth rate of 26%. Annual profit growth per farmer is limited to 1% due to rising costs unmatched by revenue increases. . This is due to the increase in the rate of business costs and the number of farmers, which is not followed by an increase in business revenue. As noted by Afriani and Yanti (2021) as well as Rinawanti *et al.* (2021), in scenarios where no modifications are applied to system components, the system functions based on its initial formulation or aligns with existing conditions as reflected in standard business analysis. However, despite the annual increase in business profits, the profit growth amounts to only 1 percent per farmer yearly. This is attributed to the escalating rate of business costs and the number of breeders, which is not matched by a corresponding increase in business revenue. Moderate scenario simulation provides the results described in Table 4.

Egg Price Increase Scenario (Optimistic)

The prevailing egg prices impact Layer chicken egg production, directly influencing business profits. Egg prices are considered a constant variable, assumed to remain fixed each year due to the multitude of factors affecting domestic chicken egg prices. In the optimistic scenario simulated within the model, it is assumed that egg prices increase at an annual rate of 6.88%, as reported by Fawzi and Alwasity (2021) and Yuhuan and Fu (2018). This is corroborated by recent national data reflecting a 6.05% increase over three months (The National Food Agency, 2025) and previous trends indicating significant regional price increases (Setiadi *et al.*, 2022; Lantarsih and Kusumastuti, 2019), which lends credence to the notion. This upward price trend yields several outcomes: (a) farmer revenue increases within a range of 1% to 27% annually; (b) farmer profits grow from 2% to 28% per year; (c) profit per individual farmer rises between 2% and 3% annually; and (d) egg production expands by approximately 15% per year. Detailed results of the simulation are presented in Table 5.

Table 5: Simulation results of the business analysis of chicken eggs in the optimistic scenario.

Year	Farmer (men)	Revenue (billion IDR)	Total Cost (billion IDR)	Profit (billion IDR)	Profit/ Farmer (billion IDR)
2016	19.93	19.096	11.257	7.839	0.393
2017	24.23	27.230	15.019	12.211	0.503
2018	30.45	34.210	18.869	15.341	0.504
2019	38.25	42.978	23.705	19.273	0.504
2020	48.05	53.994	29.781	24.126	0.504
2021	60.37	67.833	37.415	30.419	0.504
2022	75.85	85.220	47.005	38.215	0.504
2023	95.29	107.063	59.053	48.010	0.504
2024	119.71	134.505	74.189	60.316	0.504
2025	150.39	168.980	93.204	75.776	0.504
2026	188.94	212.292	117.094	95.199	0.504

Source: Research data processed.

Feed Price Increase Scenario (Pessimistic)

Egg production is influenced by two crucial variables: egg price and feed price. Egg prices tend to be constant, while feed prices tend to rise significantly. In a pessimistic scenario, feed prices are assumed to increase more substantially by 60 percent per year (Adolwa *et al*., 2021). The assumption of a 60% rise in feed costs represents a serious but manageable interruption. This is based on historical price volatility in key feed components like maize and soybean meal, which saw price increases of more than 50% during global commodities shocks like the COVID-19 epidemic (FAO, 2022; Central Bureau of Statistics, 2023). Furthermore, Indonesia's reliance on imported feed ingredients leaves the business exposed to currency changes. Between 2020 and 2024, the Indonesian rupiah fell from IDR 14,050 to more than IDR 16,300 per USD (Focus Economics, 2024), dramatically raising import expenses. Thus, a 60% increase in feed costs serves as a stress test assumption, combining global pricing volatility with currency depreciation.

The outcomes of the pessimistic scenario simulation, as presented in Table 6, indicate the following trends: (a) total business costs increase by 32% annually; (b) business profits decline substantially, ranging from a 22% annual decrease to a minimal 4% annual gain; (c) profit per farmer drops by 16% per year; and (d) egg production decreases by approximately 25% annually. The results of the pessimistic scenario simulation are shown in Table 6.

Table 6: Simulation results of the business analysis of chicken eggs in the pessimistic scenario.

Year	Farmer (men)	Revenue (billion IDR)	Total Cost (billion IDR)	Profit (billion IDR)	Profit/ Farmer (billion IDR)
2016	19.93	19.095	11.257	7.839	0.393
2017	24.23	25.477	14.921	10.556	0.436
2018	30.45	32.008	19.778	12.230	0.402
2019	38.25	40.212	26.215	13.996	0.366
2020	48.05	50.518	34.748	15.770	0.328
2021	60.37	63.467	46.058	17.409	0.288
2022	75.85	79.734	61.049	18.686	0.246
2023	95.29	100.171	80.919	19.252	0.202
2024	119.71	125.847	107.256	18.591	0.155
2025	150.39	158.103	142.166	15.937	0.106
2026	188.94	198.627	188.438	10.189	0.054

Source: Research data processed.

Model Validation

Model validation was conducted by comparing the simulation outputs with empirical data from the real-world system, with particular attention to the variables of layer chicken population and egg production. This process involved aligning the simulated results with observed data from 2016 to 2020 to evaluate the model's accuracy and reliability. A summary of the simulation results is presented in Table 7.

Table 7: Validation of chicken egg production model using MAPE.

Year	Real Production (kg/week)	Simulated Production (kg/week)	Error (%)
2016	735,072	737,221	0.29
2017	939,049	876,642	6.65
2018	1,102,300	1,004,957	8.83
2019	1,104,201	1,152,055	4.33
2020	1,148,878	1,210,683	6.25
Mean Absolute Percentage Error (MAPE)			5.09

Source: Research data (processed). Note: MAPE indicates the average absolute error between simulated and actual values across the 2016–2020 period.

In the validation of the chicken egg production model in Lima Puluh Kota Regency (LKR), the variable evaluated was the total volume of egg production. The validation process yielded a value of 5.09%, indicating that the constructed model is deemed "appropriate" for estimating chicken egg production in LKR from 2016 to 2026.

Policy Directions for Developing Sustainable Agropolitan Areas through Laying Hen Farming

The second objective of this study is to propose alternative policies that support sustainable agropolitan area development through increased egg production. The developed dynamic system model for chicken egg production in LKR effectively captures the state of broiler egg production. The simulation outcomes reveal a continuous growth in chicken egg production until 2026. Various scenarios were considered in the model, including 1) a scenario without changes in components (moderate); 2) a scenario with increasing egg prices (optimistic); and 3) a scenario with rising feed prices (pessimistic).

Based on the description of the simulation results of various scenarios, policy directions for the development of agropolitan areas in LKR can be made as described below;

Moderate scenario (without component change): In this scenario, all input and output components remain constant over time. The production system continues to grow based on its current trajectory, without significant shocks or improvements. Support gradual capacity building for small and medium-scale layer farmers through training in maintenance, biosecurity, and farm business management. Encourage farmer cooperatives to enhance collective bargaining power and facilitate easier access to marketing channels and inputs. Maintain stable support policies such as access to veterinary services, infrastructure development (roads, electricity), and moderate subsidies for feed or DOC to keep the system resilient. Promote moderate reinvestment incentives to allow existing farmers to scale up sustainably without overburdening the system.

Optimistic scenario (egg price increase): In this optimistic scenario, a significant rise in egg prices leads to increased revenue and profit for farmers, attracting new entrants and encouraging expansion. The directions that can be given in this scenario are: Strengthen production capacity by promoting investment in modern equipment, automated systems, and vertical integration to meet rising demand. Develop export facilitation policies to take advantage of regional or international markets and diversify income streams. However, it should be highlighted that livestock exports, particularly chicken eggs, suffer a number of major trade restrictions. Indonesia's export rules, food safety certification standards, and complex licensing procedures might hinder access to foreign markets. As a result, supportive policies should focus on streamlining the regulatory process, enhancing product quality and safety standards, and strengthening the capacity of business actors to meet export criteria. This strategy is projected to boost the worldwide competitiveness of coated egg products while also promoting the expansion of the livestock sector in the LKR.

Improve environmental regulations to ensure that rapid expansion does not result in ecological degradation (e.g., through better waste management, use of agricultural waste for feed or energy), and Support rural employment programs to accommodate increased labor demand and reduce rural-to-urban migration.

Pessimistic scenario (feed price increase): In this scenario, a spike in feed prices significantly increases production costs, reducing farmer profits and potentially forcing small-scale farmers out of the business. To ensure the retention of farmers in the agropolitan area, it is essential to formulate appropriate policy directions, which include the following:

Subsidize. To ensure the long-term viability of subsidy policies such as feed subsidies or DOC, regional budget availability and fiscal capability must be taken into account. Potential financing sources include the provision of the Regional Revenue and Expenditure Budget (APBD) through the Livestock Service or the Food Security Service, as well as national initiatives aimed at improving food security and alleviating poverty. In addition, a public-private partnership plan can be used to support program financing. Although this study did not undertake a thorough fiscal simulation, future policy planning should include a cost-benefit analysis and predicted fiscal impact to ensure that subsidies are implemented in a measurable and sustainable manner.

Stabilize feed costs by developing local feed production industries using agricultural by-products or alternative protein sources (e.g., maggot meal, fermented feed). Encourage feed efficiency strategies such as selective breeding, improved nutrition management, and the use of precision feeding technologies. Provide emergency credit schemes or risk insurance for smallholder farmers to maintain business continuity during price shocks, and promote diversification at the farm level, including integration with crop farming (e.g., using manure for fertilizers), to buffer against income loss from egg production.

Across all simulated scenarios, chicken egg production in Lima Puluh Kota Regency (LKR) exhibits a consistent upward trend, although the rate of growth tends to decelerate in response to rising feed costs. Projections indicate that overall egg production in LKR will continue to increase, along with improvements in the profitability of layer poultry farming. Nonetheless, the momentum of production growth may be hindered if feed prices escalate without a proportional increase in egg market prices.

To ensure the sustainability of agropolitan areas in LKR and the continuous generation of outputs and outcomes, the development direction must prioritize the long-term viability of the laying hen farming industry. This involves considering the long-term positive impacts and the need for adaptation to environmental changes. Stakeholders—including farmers, local communities, and other relevant parties—should be actively engaged in the planning and implementation processes to ensure ongoing support and participation (Antari *et al*., 2024). A system of regular monitoring and evaluation should be established to assess policy effectiveness, identify potential systemic changes, and develop appropriate strategic adjustments. Moreover, active communication with the community is essential to convey the benefits of policies, promote understanding of sustainable farming practices, and foster public support for the laying hen farming industry.

CONCLUSIONS AND RECOMMENDATIONS

A Dynamic system model shows that egg production in Lima Puluh Kota Regency is projected to continue increasing until 2026. However, growth may slow down if feed prices increase without an accompanying increase in egg prices. The model is useful for developing policies that support sustainable agropolitan development.

The proposed policy directions are moderate, optimistic and pessimistic scenarios. These three scenarios project egg production to increase by about 26% and profits to increase by about 2%, although growth is constrained by rising feed prices. To maintain industrial sustainability, adaptive policy support, increased livestock capacity, production efficiency, and risk protection are needed. Stakeholder engagement, periodic monitoring, and effective communication with the community.

ACKNOWLEDGMENTS

This research was financially supported by the Institute for Research and Community Service, Universitas Andalas, under Contract No: T/8/UN16.19/PANGAN-PTU-KRP2GB-UNAND/2023. The authors express their sincere gratitude to the Head of LPPM, Universitas Andalas, for providing and facilitating this funding support.

NOVELTY STATEMENT

This research introduces an innovative application of system dynamics modeling to promote sustainable development in agropolitan areas through laying hen farming in Limapuluh Kota Regency. In contrast to earlier studies that examine poultry production as a standalone issue, this study constructs an integrated, scenario-driven model that connects livestock management, socio-economic factors, and regional development policies. The model delivers valuable guidance for formulating adaptive policies in agropolitan regions facing constraints in resources and institutional support.

AUTHOR'S CONTRIBUTIONS

Dwi Yuzaria: Head of research project, Conceptualization, methodology, data curation, investigation, writing original draft, writing review, and editing.
Fitrimawati: Investigation, and writing the original draft.
Muhammad Ikhsan Rias: Data curation, investigation.

Conflict of Interest

All authors declare that they have no competing interests.

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