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1 Introduction

1.1 Background and justification

Ethiopia has one of the largest goat populations in Africa. In 2013, there were about 29 million goats in Ethiopia distributed among the major livestock production systems in the country: agro-pastoral and pastoral (70%) and the highland mixed crop–livestock production systems (30%) Livestock Sector Analysis (LSA, forthcoming 2016). Ethiopia's livestock herds are made up of multiple species of multi-purpose type. The development of intensive commercially-oriented specialized (single species or single purpose) livestock production is at an early stage. Goats are an integral part of these mixed livestock species and production systems. They are raised mainly for their meat in the highland mixed crop-livestock production systems, while they are raised both for meat and milk in the lowland agro-pastoral and pastoral livestock production systems. There are about 12 major local goat breeds raised in different agro-ecological zones of the country (Awgichew and Abegaz 2008).

Similar to large ruminants like cattle, goats also provide multiple outputs to livestock keepers: nutritious food (meat and/or milk); produce organic manure for crop production; generate cash income from the sale of live goat, meat, milk, or skins; and represent a form of asset that can easily be liquidated for emergency situations and small cash requirements. Furthermore, there are several important features of goats which can make goats more attractive to resource poor livestock keepers, compared to cattle. These include: the ability to utilize a wide range of feed types; adaptability to wide range of agro-climatic conditions; short generation intervals; small size carcasses which are affordable to smallholder farmers and low income consumers; ease of storage; and small initial investment capital requirement (Lebbie 2004). In mixed-species, goats complement cattle and sheep rather than compete with them for feed because of their inherent ability to utilize a wide variety of plant species (Lebbie 2004), resulting in efficient utilization of available scarce feed resources. Goats being very agile are also adapted to wide ranges of landscape can graze on steep land otherwise inaccessible to cattle nor suitable for crop production.

Goats are kept by a large number of pastoral and smallholder farmers in Ethiopia. For example, Negassa et al. (2011) indicate that 42% and 33% of the pastoral households and smallholder farmers, respectively, own goats. However, the number of goats kept is very small and their productivity level is also observed to be one of the lowest in eastern Africa (Negassa et al. 2011). For goat producers to benefit from the rising demand of goat meat and products, they need to have an adequate number of goats to generate sufficient marketable surpluses on a sustainable basis. Particularly, given the limited land resources for feed and environmental constraints to increasing livestock production, it is important to increase the productivity of the goats' production from the limited existing goat flock and land holdings. In this regard, an understanding of the baseline goat performance and goat flock growth dynamics is very important to identify potential targets for different interventions to increase goat producers' income and their volume of participation in live goat and goat product markets on a sustainable basis.

In general, the potential of goats' contribution towards improving farm households' income and food security situation and national economic growth in developing countries like Ethiopia is tremendous. Even though the production of goats is more popular among the lowlanders, the consumption of goat meat is becoming very popular among urban consumers in major cities like Addis Ababa. Specifically, there is an emerging consumer trend favouring the consumption of goat meat over raw beef indicting that goat sub-sector has great potential for growth. It is also observed that goat meat is lean and rich in nutrients which could attract health conscious consumers (Sebsibe et al. 2007). However, despite its economic potential, goat production is also plagued by several constraints affecting its productivity and production and hence limiting its contribution towards improving farm household income and food security, poverty reduction and national economic growth. The goat production system in Ethiopia is characterized by poor genetic performance and high level of mortality due to poor management practices and animal health services and animal diseases (Gebremariam et al. 2013; Gizaw et al. 2013; Haile et al. 2011; Negassa et al. 2011; Gizaw et al. 2010; Negassa and Jabbar 2008; Tolera 2007).

The full realization of the potential of goat production requires investment to improve goat production management especially in feed management and disease control for improving goat growth and reproductive rates along with creating enabling environment (institutions, infrastructure, and policies) to allow producers to take advantage of growing goat market opportunities. However, the investment resources are very scarce and detailed goat sub-sector sector analyses in terms of identifying and prioritizing investment opportunities and constraints in the sub-sector is critical for effective and efficient utilization of the scarce investment resources.

Currently, there are no *ex-ante* impact assessments of policy and investment interventions and *ex-ante* analytical and empirical modelling frameworks for guiding and prioritizing public and private investment decisions to promote the development of the goat sub-sector in Ethiopia. This paper develops and implements an empirical bio-economic goat flock growth model to analyse the flock growth dynamics and economics impacts of various policy/technology in interventions to inform potential policy changes and investment strategies for developing the goat sub-sector. The analysis builds on previous detailed livestock sector analyses for Ethiopia carried out by the Ministry of Agriculture and Rural Development's (MORAD) Livestock State Ministry of Ethiopia together with the International Livestock Research Institute (ILRI), using the Livestock Sector Investment and Policy Toolkit (LSIPT) developed by the World Bank, Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), and Food and Agriculture Organization (FAO) (LSIPT 2013). It focuses on detailed analyses of goat flock growth dynamics for representative livestock production systems which allows *ex-ante* impact assessment of policy and investment interventions and thus can inform and guide strategic development in infrastructure, institutional, technological and management practices that support a significant increase in goat production, productivity and commercial offtake. The modelling framework provides information on economics of goat production at different scales (flock level and production system level) and can be aggregated at regional or national level, thus making it possible to prioritize investment in the research and development of goats at the regional or national level.

1.2 Objectives of the study

The overall objective of this paper is to develop and apply an analytical and empirical modelling framework which integrates a goat flock growth model with an economic model for simulating goat meat and milk production for *ex-ante* assessment of the financial profitability of investment interventions to improve goat production in mixed crop–livestock and agro-pastoral and pastoral production systems in Ethiopia. The specific objectives are:

1. To provide a baseline characterization of goat flock demographics and flock growth dynamics over time in terms of goat flock growth rate, offtake rate, size and structure for representative production systems and flock size classes; and

2. To evaluate *ex-ante* the technical and financial impacts of combined investment interventions in health and feed management on goat production.

This paper is organized as follows. The next section provides brief description of the data used in the analysis. Section 3 presents an analytical framework guiding the empirical analysis. The empirical model used is presented in section 4, while section 5 presents the results and discussions. Finally, the conclusions, policy implications and recommendations are made in section 6.

2 The data and the scope of the study

The detailed discussion of the data sources used in this analysis is documented in the Livestock Sector Analysis report for Ethiopia (LSA, forthcoming 2016). The data has been obtained from secondary sources. First, the initial goat flock size and structure data is generated from the Living Standard Measurement Survey (LSMS) data conducted in 2010/11 jointly by the World Bank and the Central Statistical Authority (CSA) of Ethiopia (LSMS 2010/11) and from Save the Children UK livestock survey data for the pastoral areas of Ethiopia. Second, the goat demographic data (for example, fertility rates, mortality rates and offtake rates) used to generate parameters for various goat flock projection matrices was collected using the Delphi technique which involved the use of structured questionnaire to collect technical data from national and international livestock experts. The data collected using the Delphi method was validated through meetings of and discussions with panels of experts. Third, the costs of production for different livestock enterprises and prices for valuation of livestock and livestock products were also obtained from the expert interviews and secondary sources. This study focuses on agro-pastoral and pastoral and mixed crop and livestock production systems which account for the worst of the goat population and livestock dependent population. There is a trend towards intensive specialized commercial livestock production systems, but the scale is still not significant, and therefore, it is not considered in this paper.

3 Analytical framework

The analytical framework for Livestock Sector Investment Policy Toolkit (LSIPT) is a dynamic bio-economic simulation model. A non-stochastic dynamic goat flock growth model is used for the projection of goat population and outputs from goat production (meat, milk, or manure) over a fifteen year time period. The model allows the simulation of goat production outputs given the inputs required for goat production. Then, the flock model is linked with an economic model to allow for the evaluation of financial and economic profitability of goat production over the same time period based on a proper valuation of goat production inputs and outputs. The simulation analysis allows for the assessment of the technical and financial performance of the sub-sector over time given the input use, existing technologies, market conditions and policies facing the sub-sector. The analysis is conducted at the flock level, but the results of the simulation analysis can be aggregated at different levels: production system level, at regional or national level. The baseline assessment provides a counterfactual scenario ('without' intervention) against which new goat policy and investment interventions can be evaluated. Thus, it provides the basis for *ex-ante* impact assessments and benefit–cost analyses of various proposed interventions aimed at enhancing the contribution of the goat sub-sector to farm household income growth, food security, poverty alleviation and national economic growth.

4 Empirical approach

4.1 Stage-structured goat flock projection matrix model

The population projection matrices are based on Leslie (1945); Caswell (1989); Caswell (2001). Recent applications of population projection matrices to the study of livestock population growth dynamics include: Lesnoff (1999); Lesnoff (2000); Lesnoff et al. (2009); Lesnoff et al. (2012). In general, there are two types of population projection matrices which are widely used in analysing livestock and plant population growth dynamics over time. The first matrix model is called the Leslie population projection matrix model which classifies the livestock population by age, hence an age-structured matrix model (Leslie 1945). The second matrix model is called the Lefkovitch population projection matrix model which classifies livestock population by their stage of growth or life cycle and hence is called the stage-structured population projection matrix model (Lefkovitch 1965). Each approach has its advantages and disadvantages. The Leslie matrix is considered to be data intensive (for example, requires age specific demographic data) and mathematically more demanding (due to higher dimensions of matrices used) as compared to the stage-structured Lefkovitch matrix model. In terms of application also, the stage-structured matrix is more practical, for example, as the utilizations of goats or any livestock for different purposes are mainly based on stages of growth (age ranges) rather than age-specific per se. Both matrix models project the population in $t+1$ time period using the initial population at t time period and annual transition parameters. For both population projection matrices, the availability of reliable demographic data (e.g., fecundity rates and mortality rates) is critical for the accuracy of prediction. In this paper, the Lefkovitch sex and stage-structured population projection matrix model is used due to its relative computational simplicity and realistic characterization of goat growth stages.

In a Lefkovitch stage-structured goat population projection matrix model, the structure of the goat flock is defined in terms of animal numbers in different age classes and sex cohorts. Thus, the female and male goats are divided into three discrete growth stages based on age: juvenile, sub-adult and adult. In general, the stage durations for sub-adults and adult goats are assumed to be different by sex of goat and by production system analysed. The projection interval, or time step, used for the projection is one year and the overall goat population projection time horizon is 20 years. The flock growth model is run by different flock size classes and for major production systems to see the effects of flock size and production system on goat flock growth dynamics.

Mathematically, the stage-structured deterministic (non-stochastic) population projection matrix model for the analysis of goat flock growth dynamics considered here is given as a discrete time first-order difference equation:

$$n_{t+1}=An_t \qquad (1)$$

Where $\mathbf{n}_{t+1}$ denotes the 6x1 state vector of goat flock sizes by sex and by stage of goat growth at a time $t+1$; $\mathbf{n}_t$ is a 6x1 state vector of goat flock size by sex and stage of goat growth at time t; and $\mathbf{A}$ is a square 6x6 Lefkovitch annual stage-structured population projection matrix used to analyse goat population dynamics in discrete time (Lefkovitch 1965). The $\mathbf{A}$ matrix is used to generate a new state variable or vector nt+1 and contains the annual transition probabilities derived based on annual demographic rates (annual fecundity rates, annual mortality rates and annual offtake rates). In general, the Lefkovitch population projection matrix **A** is a generalization of the Leslie age-structured matrix and is given as:

$$\boldsymbol{A} = \left[\begin{array}{cccccc} 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ G_{j,s} & P_{s,s} & 0 & 0 & 0 & 0 \\ 0 & G_{s,a} & P_{a,a} & 0 & 0 & 0 \\ \hline 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{j,s} & P_{s,s} & 0 \\ 0 & 0 & 0 & 0 & G_{s,a} & P_{a,a} \end{array}\right] \quad (2)$$

where *Fa* is the fecundity of adult female goat which is the product of annual parturition rate and net prolificacy rate, the subscripts *j, s* and *a* denote juvenile, sub-adult and adult goats, respectively irrespective of the sex of the goat and $G_{i,j}$ is the probability that a goat of a given sex in stage *i* will enter the next stage *j* (*j=i+1*) in the next time period; and $P_{i,i}$ denotes the probability of an individual goat of a given sex surviving and remaining (or persisting) in the same stage *i*. The structure and formulation of Leslie and Lefkovitch matrices are similar but the difference is in terms of the columns and matrix entries. In the case of Leslie matrix, the columns of matrix A represent the age of a goat or an animal, while in the case of Lefkovitch matrix the column represents the different stages of growth. The other difference between the two is that the matrix entries in the case of Leslie matrix is given in terms of fecundities in the first row which indicate reproductive contribution for different goat growth stages and survival probabilities (p_i) across the diagonals of the matrix. On the other hand, in the case of Lefkovitch matrix, the fecundities are given in the first row, but the survival probabilities are broken down into two: the probability of an individual surviving and moving from class *i* to the stage *j* ($G_{i,j}$) and the probability of an individual surviving and remaining (or persisting) in the same stage *i* ($P_{i,i}$).

Given the duration of a goat in each stage (d_i) and the stage-specific survival probabilities, the matrix **A** entries for G_i and P_i are computed using the following formulas (Crouse et al. 1987):

$$P_i = \left(\frac{1 - p_i^{d_i - 1}}{1 - p_i^{d_i}}\right) p_i \quad (3)$$

$$G_i = p_i^{d_i} \left(\frac{1 - p_i}{1 - p_i^{d_i}}\right) \quad (4)$$

where p_i is the annual survival rate computed below following Lesnoff et al. (2000) based on sex and stage specific demographic rates: annual mortality rate (m_i) and sex-stage specific annual offtake rate (oi). The survival probability is given as follows:

$$p_i = 1 - m_i - o_i \quad (5)$$

Equation (5) indicates a self-recruiting flock growth model or endogenous population dynamics model where animals are not imported from outside the population to accelerate growth (Lesnoff 2012). Thus, the goat demographic behaviour is assumed to be influenced mainly by both mortality and commercial offtake rates only. Finally, the first order difference equation (1) can be given in vectors and matrix representations as follows:

$$\begin{bmatrix} F_{j,t+1} \\ F_{s,t+1} \\ F_{a,t+1} \\ M_{j,t+1} \\ M_{s,t+1} \\ M_{a,t+1} \end{bmatrix} = \left[\begin{array}{cccccc} 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ G_{j,s} & P_{s,s} & 0 & 0 & 0 & 0 \\ 0 & G_{s,a} & P_{a,a} & 0 & 0 & 0 \\ \hline 0 & 0 & 0.5F_a & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{j,s} & P_{s,s} & 0 \\ 0 & 0 & 0 & 0 & G_{s,a} & P_{a,a} \end{array}\right] * \begin{bmatrix} F_{j,t} \\ F_{s,t} \\ F_{a,t} \\ M_{j,t} \\ M_{s,t} \\ M_{a,t} \end{bmatrix} \qquad (6)$$

Where the subscripts in the **A** matrix denote the stages of goat growth in *i* and *i+1* and the multiplication of the fecundity rate by 0.5 is to indicate the 1:1 female to male ratio at birth assumed in the model since this represents the natural breeding system. Note that the matrix **A** is divided into sex-stage specific blocks as indicated by the horizontal line, the entries in the upper block are for the female goat (F), while the entries in the lower blocks are for the male goat (M). The basic assumption of the above transition matrix is that only adult females can produce newborn calves hence female dominant matrix model (Lesnoff 1999).

Once the transition matrix **A** is set-up, the next step in the analysis of goat flock dynamics is to find out the eigenvalues and eigenvectors of the population projection matrix **A**. Several important parameters which characterize the goat flock dynamics emerge from the eigenvalue and eigenvector analyses of the transition matrix **A**. First, the dominant eigenvalue (λ) of matrix A represents the finite (asymptotic) goat population multiplication rate while log (λ) gives intrinsic annual growth rate which is the continuous growth rate per individual goat in the population. Thus, in the long-run the goat population follows exponential growth rate given by log (λ) or:

$$\lambda = e^{r} \qquad (7)$$

$$\lambda^{t} = e^{rt} \qquad (8)$$

Since **A** is 6X6 square matrix there are six possible eigenvalues and six associated eigenvectors with matrix **A**. However, the annual rate of increase of the population is given by the dominant eigenvalue. The eigenvalues are defined as the solutions to the characteristic equation:

$$det(\mathbf{A} - \lambda \mathbf{I}) = 0 \qquad (9)$$

where *det* denotes determinant and **I** is an identity matrix. The sign of λ indicates whether the flock size (or population) is declining (λ <1), the goat flock size is staying constant (λ=1), or the goat flock size is increasing (λ >1) in the longrun and shows that potential exists for increased commercial offtake above the current level. For example, λ equal to 1.2 means population increases by 20%/year and λ equal to 0.93 means the population will decrease by 7%/year over the long-run. Second, the normalized eigenvector (*w*) associated with the dominant eigenvalue gives the stable stage-structured proportion for goat flock size. Third, the standardized eigenvectors (*v*) associated with the dominant eigenvalue of the transpose of matrix **A** provide the reproductive values of different stages of goat production as compared to the juvenile, this measures the relative contributions of different stage of goat growth to long-term growth in goat flock size.

It is also important to note that several important simplifications of the presentation of the projection matrix model can be made once the dominant eigenvalue and the associated eigenvector are determined. These simplifications are useful for projection purposes. First, there is equivalence between the transition matrix and the dominant eigenvalue and as a result the following relationship holds at equilibrium:

$$\boldsymbol{Aw} = \lambda * \boldsymbol{w} \qquad (10)$$

From equation (10) it follows that the goat projection equation (1) can be alternatively given as:

$$\boldsymbol{n}_{t+1} = \lambda * \boldsymbol{n}_{t} \qquad (11)$$

For *T* large, λ is also approximated by annual empirical multiplication rate given as the ratio of N_{t+1} to Nt where N represents the total herd size for age groups and sex at a given time. Equation (1) can be also generalized to give the goat projection model at any time t given the initial flock size and stable flock proportion as:

$$\boldsymbol{n_t} = n_0 * w \qquad (12)$$

Where n_t is a vector of goat population at time *t;* n_0 is scalar and denotes the initial goat flock size; λ is the dominant eigenvalue and **w** is the normalized eigenvector associated with the dominant eigenvalue and denotes stable stage population proportions. Similarly, given the stable sex and stage distribution, and asymptotic goat growth rate, the total commercial live goat offtake for goat with i^{th} sex in j^{th} growth stage at any time *t* can be obtained using the following commercial offtake function:

$$O_{ij,t} = O_{ij} * n_0 * \lambda^t * \boldsymbol{w} \qquad (13)$$

Where $O_{ij,t}$ is a vector of commercial offtake of the i^{th} sex in j^{th} growth stage at t time. The total carcass equivalent commercial live goat offtake at a given time period is given by aggregating the carcass offtake rates across sex and stage classes. This shows the quantity of commercial offtake with constant goat growth rate and stable stage-structure **w**.

It is also possible to compute steady-state commercial offtake which is characterized by the equilibrium situation whereby the growth rate is zero. The simulation analysis to see the effects of different interventions is usually conducted for steady state situation to avoid bias due to change in goat flock size and structure. For steady-state situation since λ is equal to 1, the goat flock projection model given in equation (11) is modified as:

$$\boldsymbol{n_t} = n_0 * w \qquad (14)$$

and accordingly the commercial offtake function can be also modified as:

$$O_{ij,t} = O_{ij} * n_0 * \boldsymbol{w} \qquad (15)$$

The steady state offtake rate is a constant while the goat flock size or population remains constant over time. This is a desirable management strategy whereby a regular offtake is made thereby producing regular income and returning the goat population to a stable size and structure. This is important particularly when there is a need to limit the size of the goat population due to the need to match livestock numbers to available feed resources. This objective is achieved through numerical manipulation of the transition matrix whereby the λ is equated to 1 and the offtake rates are choice variables selected using non-linear optimization technique.

One of the important goals of the analysis of goat flock growth dynamics is to determine what stages and what demographic rates are most likely causing the increase or decrease in the goat flock. This is important because resources are limited so priority areas of development and research interventions need to be identified. For this purpose, sensitivity and elasticity analyses are made in order to assess the impacts of changes in goat demographic factors (reproductive rates and mortality rates) on long-term goat growth rate (λ). The sensitivity is calculated from the elements of the right and left eigenvectors (**w** and **v**, respectively) as follows (de Kroon et al. 2000):

$$S_{ij} = \frac{\partial\lambda}{\partial a_{ij}} = \frac{v_i w_i}{\langle w, v\rangle} \qquad (16)$$

Where *v* is the left eigenvector associated with **A**, and <**w, v**> is the scalar product of vectors *w* and *v*. The sensitivity analysis estimates the impact of an absolute change in the demographic rates on population growth rate. High sensitivity values indicate that little intervention could have large impact in goat population growth. However, the problem with the sensitivity analysis is that the values of sensitivity analysis cannot be compared among different demographic parameters when different scales or units are used. Therefore, instead, the unit-free elasticity is calculated from the elements of the transition matrix (a_{ij}) in **A**, the population growth rate, and the elements of the right and left eigenvectors (*wi* and *vi*) as follows (de Kroon et al. 2000):

$$\varepsilon_{ij} = \frac{a_{ij}}{\lambda}\frac{v_i w_i}{\langle w, v\rangle} = \frac{\partial \log(\lambda)}{\partial \log(a_{ij})} \quad (17)$$

Where ‹w,v› is the scalar product of the two vectors defined as before. The elasticity analysis estimates the effect of a proportional change in the demographic rates on population growth rates. Elasticities are unitless, represent the proportional contribution to λ and are often considered easier to interpret than sensitivities, particularly, when the matrix elements are measured in different units or operate on different scales (e.g. survival rates and fecundity rates) (de Kroon et al. 2000).

Since the elasticities are proportions they all sum to one and this property allows us to assess the proportional contribution of each matrix element to λ. For each column of the matrix A, which correspond to the individual stage, the elasticity values across the rows can be summed to assess how the different stages in goat production contribute to the goat growth rate. Similarly, for each row, the sum of elasticity can be made across the columns to assess the relative contribution of the different demographic rates to goat growth rate (for example, fecundity rates and mortality rates). Thus, the analysis of the elasticity helps to identify the stage where the smallest changes in demographic rates will produce the biggest change in the population growth rate and hence this helps to prioritize intervention efforts. Different scenario analyses can also be conducted to take into account the degree of uncertainty and/or variation in the input parameters in the projection matrix. For scenario analysis different values for demographic rates can be used to reflect uncertainty and variation. It is also important to note that the asymptotic multiplication rate of all or part of the population depends on the female demographic rates hence female dominant flock model (Lesnoff 1999). It is indicated that the male demographic rate affects the sex ratio in the population and the age structure of the male goat flock only.

The goat flock projection model used here allows us to estimate various outputs from the goat production over time: commercial offtake of live goat (and its meat equivalents), milk and manure production by different classes of goat, flock sizes and production systems. In order to measure the productivity, feed requirements and outputs, the special case of a steady state (or zero growth rate) flock, achieved by adjustment of the offtake rates is used. This is particularly important to obtain an unbiased estimate of the impacts of interventions. The steady-state is obtained by the re-parameterization of the population projection matrix **A** such that the dominant eigenvalue of the re-parameterized matrix **A** is equal to 1. The parameterizing is done by changing the commercial offtake rates numerically.

4.2 Economic model

The economic model to analyse the financial and economic profitability of goat production 'with' and 'without' policy and investment interventions is based on a capital budgeting approach. This approach requires a stream of costs and benefits to be reduced to a comparable present worth using the process of discounting as outlined in Gittinger (1982).

Baseline assessment of financial profitability

The financial viability of goat production 'without' intervention is assessed by goat flock size classes and production systems using the present value (*PV*) of annual gross margins (*GM*) generated from goat production over the time horizon of 20 years. The *GM* is given as the difference between the total revenue (TR_t) of multiple outputs (meat, milk, or manure depending on the goat production system considered) generated from goat enterprise and variable costs (VC_t) associated with goat production for stable goat flock size and structure. The major variable costs include: costs of veterinary drugs, medicine and mineral supplements. The goat management affects the reproduction rates and mortality rates which in turn affects the performance of goat in different production systems by affecting the rate of goat flock growth and potential offtake. The flock growth model is linked to the economic model whereby the offtakes from the flock growth model are monetized.

Mathematically, the present value of the gross margin (*PVGM*) for a given flock size class is given as:

$$PVGM = \sum_{t=0}^{T} \frac{(TR_t - VC_t)}{(1+\delta)^t} = \sum_{t=0}^{T} \frac{GM_t}{(1+\delta)^t} \tag{18}$$

Where *T* is the assumed relevant planning time horizon in years; δ is the discount rate (10% assumed); GM_t is the annual gross margin accrued in period *t*. The *GM* represents return to farm household's labour, land and capital in goat production and is considered a farm gate measure of the gross domestic product (*GDP*) for goats. In general, the higher the *PVGM* is the better. Furthermore, if the availability of data allows, the net profit for goat production can be obtained as the difference between the *GM* and the fixed costs. The net profit indicates the extent to which the goat producers are earning normal or excess profits and thus reflects the level of competition and risk existing in the goat sub-sector. However, due to lack of data on the fixed costs for individual farm households it was not possible to compute the net farm income or net profits for the goat production systems.

The life cycle of livestock production is different by livestock species and production systems due to the difference in the biology and objectives of production in different production systems which affect the length of project or time horizon of the project. In such situations, when project time horizons are different, for comparing the *GM* for different livestock enterprises or crop enterprises, it is important to analyse the *GM* in terms of annual equivalent cash flows. Thus, the annualized present value of gross margin (*APVGM*) is given as:

$$APVGM = PVGM * \frac{\delta * (1+\delta)^t}{(1+\delta)^t - 1} \tag{19}$$

Once the *APVGM* is derived it can be combined with the geographic information system (GIS) data and goat population data to generate the goat *GM* at herd or household level for aggregation at different levels. The computed *GM* could be mapped by assigning it to the mapped goat population in a given production system or for the country as a whole. This approach allows us to assess the geographic magnitude and distribution of benefits of intervention and to match their level of interventions and expenditures to potential benefits (Thornton and Herrero 2014).

Ex-ante impact assessment

Financial profitability

The financial feasibility of goat policy and investment interventions is analysed using a multi-year partial budgeting framework (Gittinger 1982). The partial budgeting implies that only the costs and benefits which differ between the 'with' and the 'without' policy and investment interventions had to be considered. Therefore, the net incremental cash flow (given as a difference between incremental benefits and incremental costs) from the policy and investment interventions over a given planning time horizon (T) is derived and analysed using three principal financial measures: (1) net present value (*NPV*), (2) benefit cost ratio (*BCR*), and (3) internal rate of return (*IRR*) (Gittinger 1982).

The net incremental cash flow (CF_t) due to the policy and investment interventions at time *t* is mathematically given as:

$$CF_t = (B_t^w - B_t^{WO}) - (C_t^W - C_t^{WO}) \tag{20}$$

Where B_t^w and B_t^{WO} are the monetary benefits of the 'with' and 'without' interventions, respectively, and C_t^w and C_t^{WO} are the costs of the 'with' and 'without' interventions, respectively. Then, the net present value (*NPV*) of net incremental cash flows from the policy and investment interventions over a T-year planning time horizon is given as:

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{(B_t^w - B_t^{WO}) - (C_t^W - C_t^{WO})}{(1+\delta)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+\delta)^t} \quad (21)$$

Where δ is the discount rate assumed to be 10%; I_0 is the initial investment cost to be realized over the period *t=0*; and other variables are defined as before. The *NPV* provides a basis on which to determine whether the return on a project will be positive or negative and with which to compare different potential projects. As a rule, projects with positive *NPV*s are accepted.

The annualized present value of net incremental benefit (*ANPV*) from 'with' policy and investment intervention for a given flock class in a given production system is given as follows:

$$ANPV = NPV * \frac{\delta * (1+\delta)^t}{(1+\delta)^t - 1} \quad (22)$$

Where *NPV* is the net present value of net incremental benefit and the other variables are as defined as before. The income impact of the intervention is also assessed in terms of annual net incremental benefit generated per individual goat and net incremental benefit per capita.

In addition, the benefit cost ratios (*BCR*s) and the internal rate of returns (*IRR*s) are also calculated for the net incremental benefit from the interventions. The *BCR* measures the total financial return for each money invested in goat production and provides a measure of the efficiency with which the limited funds are utilized to generate the realized benefits. The *BCR* criterion measures the effectiveness of investment and is very important in a situation where several projects are competing for the same limited funds. Based on the *BCR* investment criterion, it is advisable to invest if the *BCR* is greater than 1 and the priority is given for the project with the higher or highest *BCR*. The *BCR* is given by the following formula:

$$BCR = \sum_{t=0}^{T} \frac{(B_t^W - B_t^{WO})}{(1+\delta)^t} \Big/ \sum_{t=0}^{T} \frac{(C_t^W - C_t^{WO})}{(1+\delta)^t} + I_0 \quad (23)$$

Finally, the *IRR* of the net incremental cash flow for the 'with' intervention situation is obtained. The *IRR* is a discount rate that, when applied to the future streams of project costs and benefits, produces a *NPV* of zero. It expresses the returns to the investment in the project as an interest rate. It, therefore, permits the comparison of the returns to investment in the current project with the returns to investment in other possible projects or to simply investing the funds in an interest earning bank account. Then, in order to make an investment decision, the value of *IRR* is compared with the cost of capital. For example, the value of *IRR* greater than the current lending rate indicates that the investment is profitable. In other words, the investment must satisfy the condition that *IRR* is greater than δ to justify initial investment interventions. This indicates that the degree to which the return to a goat investment intervention is comparable to returns to alternative investment options elsewhere and hence competes for the available funds. Mathematically, the *IRR* is expressed as:

$$-I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+IRR)^t} = 0 \quad (24)$$

Where CF_t is the net incremental cash flow at time *t* and *IRR* is the internal rate of return. The idea is to solve equation (24) for the *IRR*. The *IRR* is solved by trial and error using Microsoft Excel.

Future production–consumption balances

The impact of policy and investment interventions in goat production is also assessed in terms of to what extent it contributes towards closing the growing future production-consumption gaps for goat meat and milk in Ethiopia. The computation of current and projected goat and milk production is made using a deterministic 20-years flock growth model as discussed in section 3. On the other hand, the computation of current and projected goat and milk consumption requirements is made using the information on income elasticity of demand for goats and milk, growth in real per capita GDP and human population. Thus, the projected per capita consumption of goat meat (or milk) is given as:

$$C_t = C_0 * (1 + \eta * \gamma)^t \quad (25)$$

Where C_t is the projected per capita goat meat (or milk) consumption for a given year *t*; C_0 is a baseline per capita consumption of goat meat (or milk); η is the income elasticity of demand for goat meat (or milk); and γ is the trend annual growth rate of real per capita GDP. Then, the projected total consumption of beef (or milk) for future time period *t* (*TCt*) is obtained by multiplying the projected per capita consumption with the projected population (*POPt*) for that given period of time:

$$TC_t = C_0 * (1 + \eta * \gamma)^t * POP_t \quad (26)$$

In this projection, the human population projection is based on the CSA population projection for medium variant population growth scenario for Ethiopia. Thus, the annual trend growth rate for real per capita GDP is obtained by taking the difference between the average GDP and population growth rates over the last seven years (2007–13). Based on estimates by International Food Policy Research Institute (IFPRI), the income elasticity estimates used in the projections of meat and milk consumptions are derived from household income, consumption and expenditure survey data for 2004/05 (Tafere et al. 2012). The income elasticity estimate for meat and dairy products (including milk) is 0.939 and 0.420, respectively (Tafere et al. 2012).

5 Results and discussions

5.1 Results of baseline assessments

Agro-pastoral and pastoral production systems: Parameterization of the goat flock growth model

Baseline goat flock size and structure

In the LG system, three representative goat production systems are considered and the baseline goat flock size and structure for the LG production systems used in calibrating the goat flock projection matrices is given in Table 1. The average flock size for agro-pastoral systems is 15, while the average goat flock size for small and medium flock size pastoral system is 9 and 25 heads of goat, respectively. The structure of goat flocks is analysed at two levels, globally and by sex. Globally (combining all sexes and stages of goat growth), the goat flock in both agro-pastoral and pastoral production systems are dominated by females. The females in agro-pastoral flocks account for 77%, while the males account for about 24% of the goat flock. The proportion of female goats in pastoral small size flocks is 79%, while in the case of pastoral medium-sized flocks the proportion of female goat is 74%. In general, growth stage-wise the adult goats are dominant, while sex-wise the female goat are dominant in the goat flock for agro-pastoral and pastoral production systems. The age-sex structure of goat flock in LG clearly indicates the focus of agro-pastoralists and pastoralists is on reproduction and milk production.

Table 1. Baseline initial goat flock size and structure for agro-pastoral and pastoral production systems

Stage class	Agro-pastoral			Pastoral—small flock size			Pastoral—medium flock size		
		Flock structure			Flock structure			Flock structure	
	Flock size	Global	Intra-sex	Flock size	Global	Intra-sex	Flock size	Global	Intra-sex
Young female (F_j)	3.9	0.26	0.34	1.44	0.16	0.20	5.0	0.20	0.27
Sub-adult female (F_s)	0.9	0.06	0.08	1.35	0.15	0.19	3.2	0.13	0.18
Adult female (F_a)	6.7	0.45	0.58	4.32	0.48	0.61	10.2	0.41	0.55
Young male (M_j)	2.7	0.18	0.78	1.17	0.13	0.59	2.7	0.11	0.42
Sub-adult male (M_s)	2.4	0.03	0.13	0.18	0.02	0.09	1.2	0.05	0.19
Adult male (M_a)	0.3	0.02	0.09	0.63	0.07	0.32	2.5	0.10	0.38
Total	15			9			25		

Goat flock demographic rates

The detailed initial stage-specific demographic rates used in calibrating the goat flock projection matrices for agro-pastoral and pastoral production systems are given in Table 2. The goat demographic rates vary by sex, stage of growth and production systems. The data on demographic rates include: class age range in years, stage duration in years, annual mortality rates, annual survivorship rate and annual fecundity rates. It is important to note that the observed mortality rate is about 26% and is similar for male goats and female goats but higher for younger goats as compared to older or mature goats. Due to a lack of data, similar levels of commercial offtake rates are assumed for both agro-pastoral and pastoral production systems. The initial assumed annual survival rate is also similar across different production systems because of the assumed similar levels of annual mortality and annual offtake. In general, the baseline goat flock in agro-pastoral and pastoral production systems is characterized by high mortality rate (varied from 10–29%) and low fertility rate (varied from 65–72%). The observed annual fecundity rate among the reproductive adult female goats is considered very low and varies only from 66–72%.

Table 2. Initial stage-specific demographic rates used in calibrating goat flock projection matrices for agro-pastoral and pastoral production systems

Stage class	Class age range in years	Stage duration in years (d_i)	Annual mortality rate (m_i)	Annual offtake rate (o_i)	Annual survival rate (s_i)	Annual fecundity rate (F)
Agro-pastoral						
F_j	0–0.5	0.5	0.26	0.00	0.74	0.00
F_s	0.5–1.5	1	0.12	0.09	0.79	0.00
F_a	1.5–6.5	5	0.10	0.10	0.80	0.66
M_j	0–0.5	0.5	0.26	0.07	0.67	0.00
M_s	0.5–1.5	1	0.12	0.05	0.38	0.00
M_a	1.5–4	2.5	0.10	0.17	0.73	0.00
Pastoral—small flock size						
F_j	0–0.5	0.5	0.29	0.00	0.71	0.00
F_s	0.5–1.5	1	0.12	0.09	0.79	0.00
F_a	1.5–6.5	5	0.10	0.10	0.80	0.65
M_j	0–0.5	0.5	0.24	0.05	0.71	0.00
M_s	0.5–1.5	1	0.12	0.55	0.33	0.00
M_a	1.5–4	2.5	0.10	0.17	0.73	0.00
Pastoral—medium flock size						
F_j	0–0.5	0.5	0.24	0.00	0.76	0.00
F_s	0.5–1.5	1	0.14	0.09	0.77	0.00
F_a	1.5–6.5	5	0.10	0.10	0.80	0.72
M_j	0–0.5	0.5	0.24	0.05	0.71	0.00
M_s	0.5–1.5	1	0.12	0.55	0.33	0.00
M_a	1.5–4	2.5	0.10	0.17	0.73	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral goat flocks are given in Table 3. The population projection matrices are derived using the demographic rates given in Table 2. The matrix is applied to initial goat flock to provide goat flock growth dynamics over time. The parameters of population projection matrix determines whether the goat flock is declining, held constant or growing over time. The parameters also reflect the state of livestock productivity development and affected by the changes in policy and investment interventions.

Table 3. Annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral goat flocks

	Stage at year t					
Stage at year *t+1*	F_j	F_s	F_a	M_j	M_s	M_a
Agro-pastoral						
F_j	0.00	0.00	0.53	0.00	0.00	0.00
F_s	0.74	0.32	0.00	0.00	0.00	0.00
F_a	0.00	0.47	0.80	0.00	0.00	0.00
M_j	0.00	0.00	0.53	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.67	0.15	0.00
M_a	0.00	0.00	0.00	0.00	0.23	0.73
Pastoral—small flock size						
F_j	0.00	0.00	0.52	0.00	0.00	0.00
F_s	0.71	0.31	0.00	0.00	0.00	0.00
F_a	0.00	0.48	0.80	0.00	0.00	0.00
M_j	0.00	0.00	0.52	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.71	0.13	0.00
M_a	0.00	0.00	0.00	0.00	0.20	0.73
Pastoral—medium flock size						
F_j	0.00	0.00	0.58	0.00	0.00	0.00
F_s	0.76	0.31	0.00	0.00	0.00	0.00
F_a	0.00	0.45	0.80	0.00	0.00	0.00
M_j	0.00	0.00	0.58	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.71	0.13	0.00
M_a	0.00	0.00	0.00	0.00	0.19	0.73

Simulation of baseline flock growth dynamics

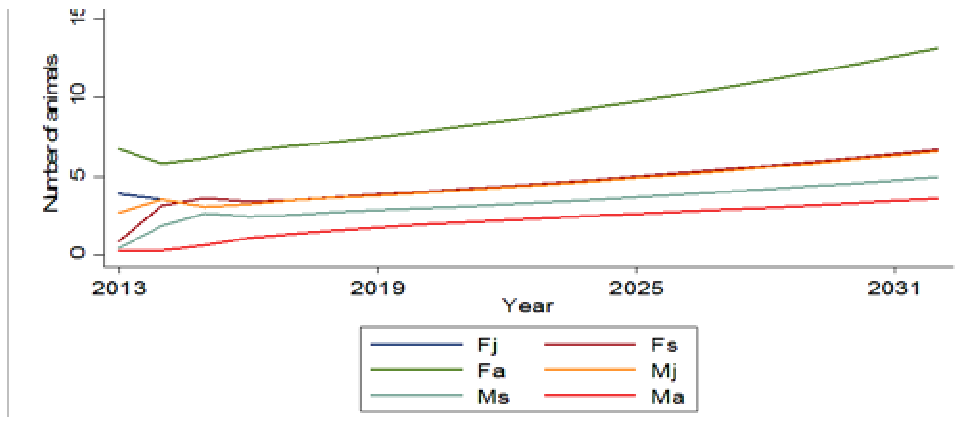
Goat flock growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term goat population multiplication rates for agro-pastoral and pastoral production systems are given in Table 4. The projected number of goats by different classes for agro-pastoral production systems are given in Figures 1, 2, and 3. There is upward trend in number of goat for all goat types and increase is especially noticeable for female adult goats. Under the baseline scenario, the long-run goat multiplication rate for agro-pastoral production system is 1.04 which implies a 4% goat growth rate per year. The stable stage distribution associated with this constant goat growth rate is 16%, 16%, 31%, 16%, 12%, and 9% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male goat, respectively. The stable stage distribution is also dominated by female goats, especially adult females. As compared to the initial goat flock structure, the stable flock growth results in lower proportion of sub-adult females and substantially higher proportion of adult male goats. This might be because more adult female goats are required to reproduce and maintain the flock given higher mortality rate. The adult females contribute most to goat reproduction. Similar stable stage distribution and stage-specific reproductive values are observed for both small and medium size flock pastoral production systems.

Table 4. Baseline stable stage distribution (w), stage-specific reproductive values (v) and annual long-term population multiplication rate for agro-pastoral and pastoral goat production systems

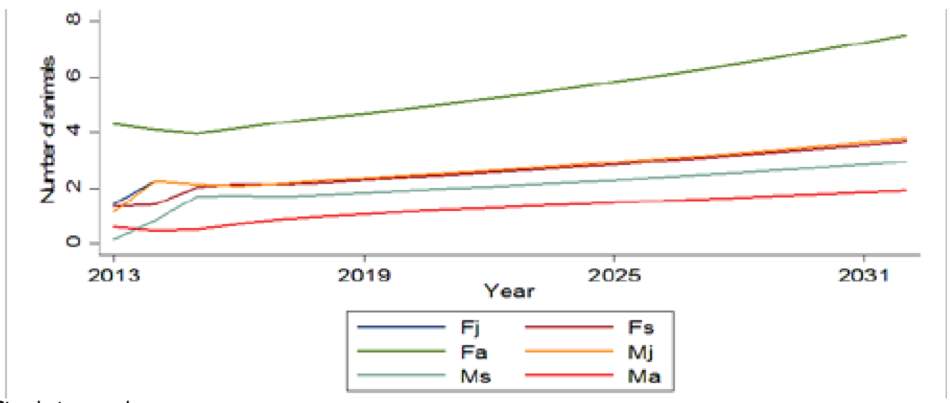
Sex-stage class	Agro-pastoral		Pastoral—small flock size		Pastoral—medium flock size	
	w	V	w	V	w	V
F_j	0.16	1.00	0.16	1.00	0.16	1.00
F_s	0.16	1.41	0.16	1.46	0.17	1.39
F_a	0.31	2.16	0.32	2.21	0.30	2.26
M_j	0.16	0.00	0.16	0.00	0.16	0.00
M_s	0.12	0.00	0.12	0.00	0.13	0.00
M_a	0.09	0.00	0.08	0.00	0.08	0.00
λ	1.04		1.04		1.05	

Figure 1. Number of goats by sex and stage of growth, agro-pastoral herd.



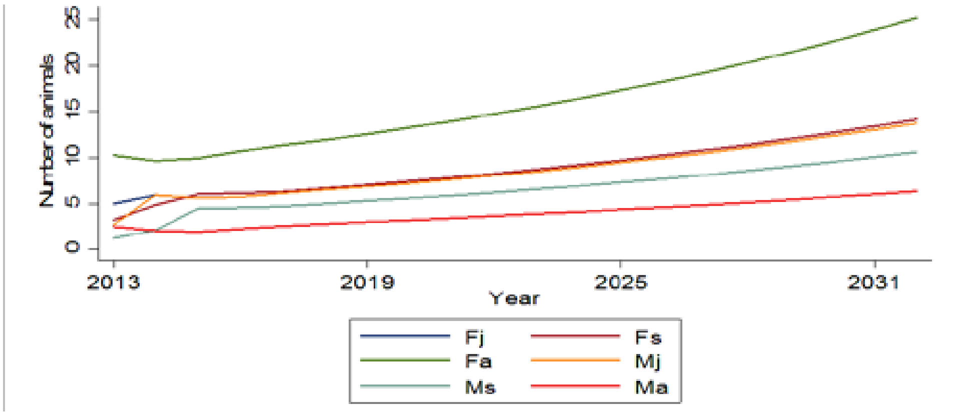
Simulation work.

Figure 2. Number of goats by sex and stage of growth, pastoral small herd.



Simulation work.

Figure 3. Number of goats by sex and stage of growth, pastoral medium herd.



Simulation work.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for agro-pastoral and pastoral production systems are given in Table 5. The sensitivity and elasticity analyses provide measures which indicate the degree to which changes in demographic rates in the projection matrix result in a change in the population trend (Caswell 1989). The results of elasticity analysis shows that the long-term goat population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival contributes about 49% to the goat flock growth trend. The annual population growth rate is second most elastic to the probability that sub-adult female survives and stays as a sub-adult and the juvenile female survives and transition to the sub-adult female. Specifically, a 1% increase in juvenile female and sub-adult female goat survivorship results in about 15% and 21% increase in annual multiplication rate, respectively. In terms of stages of growth, it is also important to note that young female goats, sub-adults and adults stages contribute 15%, 21%, and 64%, respectively, to goat flock growth. This result makes sense and is expected since adults are mainly responsible for reproduction. Furthermore, it is also important to note that the female goat fertility contributes only 15%, while the annual survival contributes about 85% to the goat growth rate. Thus, it is more important to reduce the mortality rate than improving fertility to increase goat population growth in both agro-pastoral and pastoral production systems. This indicates the importance of identifying the causes of goat mortality and implementing cost-effective measures to reduce it. However, it should be also noted that since there is low level of goat productivity, improving the fertility of goats should also be addressed after mortality is improved.

Table 5. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for agro-pastoral and pastoral goat production systems

	Sensitivity matrix			Elasticity matrix			
	F_j	F_s	F_a	F_j	F_s	F_a	Total
Agro-pastoral							
F_j	0.00	0.00	0.29	0.00	0.00	0.15	0.15
F_s	0.21	0.21	0.00	0.15	0.06	0.00	0.21
F_a	0.0	0.33	0.64	0.00	0.15	0.49	0.64
Total				0.15	0.21	0.64	1.00
Pastoral—small flock size							
F_j	0.00	0.00	0.29	0.00	0.00	0.15	0.15
F_s	0.21	0.21	0.00	0.15	0.06	0.00	0.21
F_a	0.00	0.32	0.64	0.00	0.15	0.49	0.64
Total				0.15	0.21	0.0.64	
Pastoral—medium flock size							
F_j	0.00	0.00	0.28	0.00	0.00	0.15	0.15
F_s	0.21	0.22	0.00	0.15	0.06	0.00	0.21
F_a	0.00	0.35	0.63	0.00	0.15	0.49	0.64
Total				0.15	0.21	0.64	

Simulation of steady state goat flock growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stage distribution, stage-specific reproductive values and offtake rates for agro-pastoral and pastoral production systems are given in Table 6. Under steady state the goat growth rate is zero in that the goat flock size is kept constant at the initial level. The expected changes are therefore in terms of stable stage distribution and offtake rates, as compared to the initial goat flock structure.

Table 6. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for agro-pastoral and pastoral goat production systems

	Agro-pastoral			Pastoral—small flock size			Pastoral—medium flock size		
Stage class	W	V	Offtake rate	W	V	Offtake rate	W	V	Offtake rate
F_j	0.14	1.00	0.00	0.16	1.00	0.00	0.15	1.00	0.00
F_s	0.16	1.32	0.10	0.16	1.38	0.10	0.17	1.28	0.11
F_a	0.30	1.90	0.17	0.31	1.97	0.16	0.29	1.93	0.19
M_j	0.15	0.00	0.07	0.15	0.00	0.05	0.15	0.00	0.05
M_s	0.12	0.00	0.50	0.13	0.00	0.55	0.13	0.00	0.55
M_a	0.11	0.00	0.17	0.10	0.00	0.17	0.11	0.00	0.17

The steady state production is obtained by numerically adjusting the offtake rates by sex and stage of goat growth. The goat population is growing under the baseline scenario and to obtain steady state goat production there is a need to decrease the flock size by decreasing the goat types (sex and stage) which significantly contribute to goat growth. Thus, a zero growth rate is obtained by increasing the offtake of female goats, mainly sub-adults and adult females. As a result, under steady state the percentage offtake rate of sub-adult female goat substantially increases. For example, in the case of agro-pastoral and pastoral flocks, the offtake rates for sub-adult and adult female goats increases from 9% and 10% in the baseline situation to 10% and 17%, respectively. The male offtake rates remained constant as males do not contribute to long-term goat growth. In general, the observed baseline offtake rate is below the steady state offtake rate which indicates an optimal offtake strategy practiced by livestock keepers. The reason for this practice needs to be investigated. Similar results are observed for pastoral production systems. For example, in the case of pastoral production flocks the observed baseline offtake rate for adult female goat is 10%, while the steady state offtake rate is 13%.

Goat meat production

The annual steady state net live goat offtake and equivalent carcass meat production (total carcass weight in kg) for different production systems is given in Table 7. The average net offtake is about 16% for agro-pastoral and pastoral system while it is 17% for pastoral medium flock size. For the agro-pastoral goat flock the average annual goat meat production per goat flock is 27 kg which is about two live goat equivalents. The highest annual average goat offtake of 45 kg is obtained for the medium size pastoral production system, while for small and medium pastoral flock the annual average goat production is 18 kg/flock and 45 kg/flock, respectively. In general, given the demographic factors, herd size and structure, there results show that there is limited annual live goat offtake.

Table 7. Steady state goat meat production and cumulative and annualized present value of gross margins for agro-pastoral and pastoral goat production systems in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual goat meat production from the flock (kg)[2]	Annualized present value of *GM* per goat flock (ETB)	Annualized present value of *GM* per head of goat (ETB/head)
Agro-pastoral	0.16	27	2214	148
Pastoral small flock size	0.16	18	3115	346
Pastoral medium flock size	0.17	45	3781	151

Note: [1]The time horizon for the projection is 20 years.

[2]The annual goat meat production is in carcass equivalent weight assuming 45 to 50% dressing percentage.

Financial profitability of goat production

The results of the analysis of financial profitability of goat production at steady state is given in Table 7. The income from goat production is derived from the sale of live goat and imputed value of manure in the case of agro-pastoral production system while in the case of pastoral goat production the income is derived from the sale of live goat and milk. The annualized present values gross margin (*GM*) per flock and per head are given in Table 7. The income is derived from the live goat sale, milk sales, or imputed values of manure depending on the production system. The annualized present value of *GM* per goat flock for agro-pastoral and pastoral small flocks and medium flocks is ETB2214, 3115 and 3781, respectively. The annualized present value of goat output per head of goat is also computed and found to be ETB148 for the agro-pastoral flock, while for the small and medium size pastoral flocks it is ETB346 and ETB151, respectively. There is productivity variation, small size pastoral flock is found to be most profitable.

Mixed rainfed moisture deficient (MRD) crop-livestock production system: Parameterization of goat flock growth model

Baseline goat flock size and structure

The baseline or initial goat flock size and structure for MRD production systems used in calibrating the goat flock projection matrices is given in Table 8. The observed goat flock sizes are very small for MRD. The average goat flock size for small flock MRD is 3, while the average goat flock size for medium MRD is 13 heads of goat. The structure of the flock is analysed at two levels, globally and by sex. Female goats in small flocks account for 73%, while males account for about 37%. In in the case of medium flock, the proportion of female goats is 74%. Similar to the agro-pastoral and pastoral production system, female adult goats are dominant in MRD production systems. The sex and age structure of the flock indicate the importance attached to the reproduction and milk production in goats production.

Table 8. Baseline initial goat flock size and structure for the MRD goat production system

Stage class	Small flock size	Structure		Medium flock size	Structure	
	Flock size	Global	Intra-sex	Flock size	Global	Intra-sex
F_j	0.66	0.22	0.30	2.73	0.21	0.28
F_s	0.24	0.08	0.11	1.43	0.11	0.15
F_a	1.29	0.43	0.59	5.46	0.42	0.57
M_j	0.54	0.18	0.67	2.08	0.16	0.62
M_s	0.09	0.03	0.11	0.52	0.04	0.15
M_a	0.18	0.06	0.22	0.78	0.06	0.23
Total	3			13		

Goat flock demographic rates

The detailed initial sex and sage-specific demographic rates used in calibrating goat flock projection matrices for MRD production systems are given in Table 9. The goat demographic rates varied by sex, stage of growth and production systems. It is interesting to note that the observed mortality rates are higher for younger goats as compared to older or mature goats. Due to lack of data, similar levels of commercial offtake rates are assumed for all MRD production systems. The initial assumed annual survivorship rate is also similar across different production systems because of the assumed similar levels of annual mortality rates and annual commercial offtake rates. The observed annual fecundity rate among the reproductive female goats is considered to be very low and estimated at about 79% and 81% for small flock and medium flock, respectively.

Table 9. Stage specific demographic rates used in calibrating goat flock projection matrices for the MRD production system

Stage class	Class age range in year	Stage duration in year (d_i)	Annual mortality rate (m_i)	Annual offtake rate (o_i)	Annual survivorship rate (s_i)	Annual fecundity (*F*)
Small flock size						
F_j	0–0.5	0.5	0.23	0.02	0.75	0.00
F_s	0.5–1.3	0.8	0.13	0.09	0.78	0.00
F_a	1.3–6.3	5	0.14	0.10	0.76	0.79
M_j	0–0.5	0.5	0.23	0.05	0.72	0.00
M_s	0.5–1.3	0.8	0.12	0.55	0.33	0.00
M_a	1.3–4.3	3	0.14	0.10	0.76	0.00
Medium flock size						
F_j	0–0.5	0.5	0.24	0.02	0.76	0.00
F_s	0.5–1.3	0.8	0.10	0.12	0.78	0.00
F_a	1.3–6.3	5	0.12	0.12	0.76	0.00
M_j	0–0.5	0.5	0.28	0.05	0.67	0.81
M_s	0.5–1.3	0.8	0.15	0.60	0.25	0.00
M_a	1.3–4.3	3	0.14	0.15	0.71	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrices for agro-pastoral and pastoral goat flocks are given in Table 10. The population projection matrices are derived using the demographic rates given in Table 9.

Table 10. Lefkovitch stage-structured population projection matrices for the MRD goat flock

	Stage at year t					
Stage at year *t+1*	F_j	F_s	F_a	M_j	M_s	M_a
Small flock size						
F_j	0.00	0.00	0.60	0.00	0.00	0.00
F_s	0.75	0.41	0.00	0.00	0.00	0.00
F_a	0.00	0.37	0.76	0.00	0.00	0.00
M_j	0.00	0.00	0.60	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.72	0.17	0.00
M_a	0.00	0.00	0.00	0.00	0.15	0.76
Medium flock size						
F_j	0.00	0.00	0.62	0.00	0.00	0.00
F_s	0.76	0.41	0.00	0.00	0.00	0.00
F_a	0.00	0.37	0.76	0.00	0.00	0.00
M_j	0.00	0.00	0.62	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.67	0.13	0.00
M_a	0.00	0.00	0.00	0.00	0.12	0.71

Simulation of baseline goat flock growth dynamics

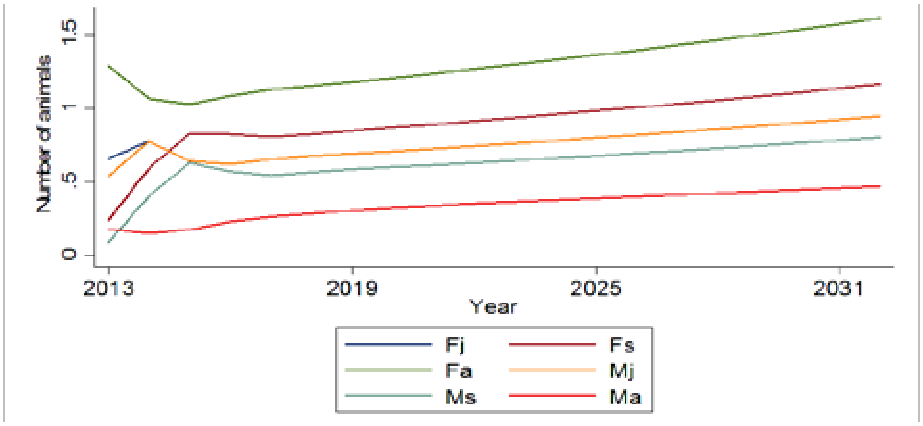
Goat flock growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term goat population multiplication rates for MRD production systems are given in Table 11. The projection of the number of animals for different classes of goats for small flock and medium flock are given in Figure 4 and Figure 5, respectively. In general, there is upward trend in number of animals for all goat types in the MRD system. It is observed that under the baseline scenario, the long-run goat multiplication rate for small and medium MRD production systems is 1.02 and 1.03, respectively, which imply annual growth rate of 2% and 3%, respectively, in goat flock size.

Table 11. Baseline stable stage distribution (w), stage specific reproductive values (v) and annual long-term population multiplication rate for the MRD goat production system

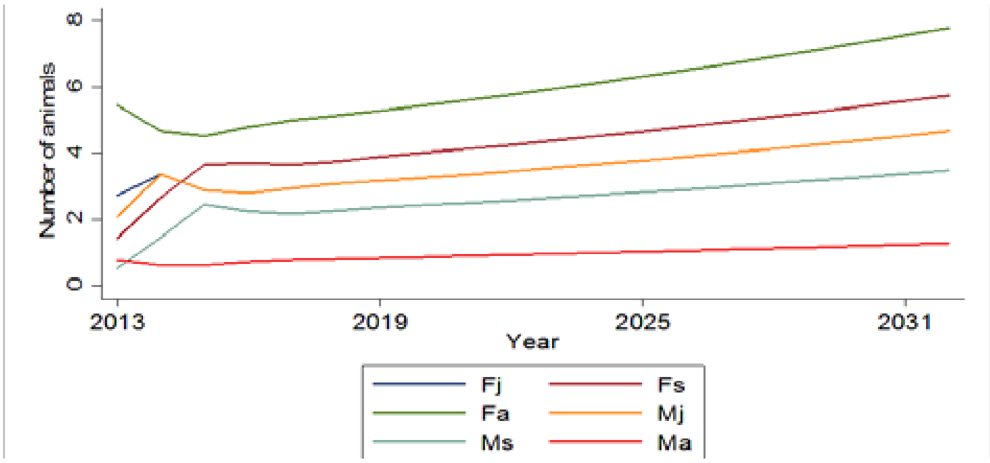
Stage class	Small flock size		Medium flock size	
	w	V	w	V
F_j	0.16	1.00	0.17	1.00
F_s	0.19	1.36	0.21	1.36
F_a	0.27	2.28	0.28	2.28
M_j	0.16	0.00	0.17	0.00
M_s	0.13	0.00	0.13	0.00
M_a	0.08	0.00	0.05	0.00
Λ	1.02		1.03	

Figure 4. Number of goats by sex and stage of growth, MRD small herd.



Simulation work.

Figure 5. Number of goats by sex and stage of growth, MRD medium herd.



Simulation work.

For small goat flock size, the stable stage distribution associated with this constant goat growth rate is 16%, 19%, 27%, 16%, 13%, and 18% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male goat, respectively. Similar to initial stage structure, the stable stage distribution is also dominated by adult females at 27% of flock size. It is also observed that the adult females contribute most to goat reproduction followed by sub-adult females. Similar stable stage distribution and stage-specific reproductive values are observed for the medium size flock MRD production system.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for MRD goat production systems are given in Table 12. Similar to agro-pastoral and pastoral production systems, the elasticity analysis shows that the long-term goat population growth rate is most elastic to the probability that an adult female survives and persists as an adult. The adult female survival contributes about 44% to the goat flock growth. The annual population growth rate is second most elastic to the probability that sub-adult female survives and transition to adult female goat. Specifically, a 1% increase in sub-adult survivorship results in about 25% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female goat, sub-adult and adult stage contribute 15%, 25%, and 60%, respectively, to goat flock growth. Furthermore, it is also important to note that the female goat fertility contributes only 15%, while annual survival rate contributes about 85% to the goat flock growth rate. Thus, it is more important to reduce mortality rate than improving the fertility rate of goats in order to increase goat growth in MRD production systems. However, due to the small flock size, fertility management also deserves due attention.

Table 12. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for the MRD goat production system

	Sensitivity matrix			Elasticity matrix			
	F_j	F_s	F_a	F_j	F_s	F_a	Total
Small flock size							
F_j	0.00	0.00	0.26	0.00	0.00	0.15	0.15
F_s	0.21	0.25	0.00	0.15	0.10	0.00	0.25
F_a	0.00	0.43	0.59	0.00	0.15	0.44	0.59
Total				0.15	0.25	0.59	0.99
Medium flock size							
F_j	0.00	0.00	0.26	0.00	0.00	0.15	0.15
F_s	0.21	0.26	0.00	0.15	0.10	0.00	0.25
F_a	0.00	0.43	0.59	0.00	0.15	0.45	0.60
Total				0.15	0.25	0.60	

Simulation of steady state goat flock growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stage distribution, stage-specific reproductive values and commercial offtake rates for MRD goat production systems are given in Table 13. The steady state goat production is obtained by numerically adjusting the offtake rates by sex and stage of goat growth. It is to be recalled that the goat population is growing under the baseline scenario and, therefore, in order to obtain steady state goat production there is a need to decrease the goat flock size by decreasing the goat classes (sex and stage) which significantly contribute to goat growth. Thus, the zero goat growth rate characterizing the steady state is obtained by increasing the commercial offtake of female goats, mainly sub-adult and adult female goats. In the case of small flock MRD, the offtake rate for sub-adult female goats remained almost the same, while for adult female the steady state offtake rate increased slightly. On the other hand, the steady state offtake rates for adult female goats increased significantly in the case of medium size flock for the MRD production system.

Table 13. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for the MRD goat production system

	Small flock size			Medium flock size		
Stage class	W	v	Offtake rate	W	V	Offtake rate
F_j	0.15	1.00	0.02	0.16	1.00	0.02
F_s	0.20	1.30	0.10	0.22	1.25	0.14
F_a	0.27	2.12	0.13	0.27	1.93	0.21
M_j	0.15	0.00	0.05	0.16	0.00	0.05
M_s	0.13	0.00	0.55	0.13	0.00	0.60
M_a	0.09	0.00	0.10	0.06	0.00	0.15

Goat meat production

The annual steady state goat meat production (total carcass weight) by different goat production systems is given in Table 14. The average live goat net offtake rate varied from 15–19%. For small goat flock the average annual goat meat production per goat flock is 6 kg, slightly less than one live goat equivalent. The average annual offtake rate for the medium goat flock size is 19%, while the average annual goat meat production is 19 kg.

Table 14. Steady state goat meat production and cumulative and annualized present value of gross margins by different goat production systems in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual goat meat production from the flock (Kg)[2]	Annualized present value per goat flock (ETB)	Annualized present value per head of goat (ETB/head)
MRD				
Small flock size	0.15	6	533	178
Medium flock size	0.19	19	2029	156

Note: [1]The time horizon for the projection is 20 years.

[2]The annual goat meat production is in carcass equivalent weight assuming 45% to 50% dressing percentage.

Financial profitability of goat production

The results of the analysis of financial probability of goat production at steady state is given in Table 14. The annualized present value of *GM* for goat production per head of goat is also given in Table 14. The annualized present value of goat output per head for small goat flock MRD is estimated to be ETB533. In the case of medium MRD, the annualized present value of *GM* for goat outputs per goat flock is ETB2029.

Mixed rainfed moisture sufficient (MRS) crop-livestock production system: Parameterization of goat flock growth model

Baseline goat flock size and structure

Size and structure affect production, productivity and income generated from goat flock. The baseline initial goat flock size and structure for the MRS production system used in calibrating the goat flock projection matrix is given in Table 15. There is only one goat flock size class identified for the MRS and the average goat flock size is six. Globally, female goats account for 73%, while the male accounts for about 27% of the goat flock. Within female goat flock, the adult female goats are dominant (59%), while within the male goat flock, the young goats are dominant (67%).

Table 15. Baseline initial goat flock size and structure for the MRS goat production system

Stage class	Small flock size	Structure	
	Flock size	Global	Intra-sex
F_j	1.32	0.22	0.30
F_s	0.48	0.08	0.11
F_a	2.58	0.43	0.59
M_j	1.08	0.18	0.67
M_s	0.18	0.03	0.11
M_a	0.36	0.06	0.22
Total	6		

Goat flock demographic rates

The detailed initial sage-specific demographic rates used in calibrating goat flock projection matrix for the MRS production system are given in Table 16. The goat demographic rates varied by sex, stage of growth and flock size. The level of stage-specific demographic rates assumed in MRS in calibrating the goat flock projection matrices is similar to those in other goat production systems. In general, there is high goat mortality rate in the MRS production system.

The initial assumed annual survivorship rate is also similar across different production systems because of the assumed similar levels of annual mortality rates and annual commercial offtake rates. The observed annual fecundity rate among the reproductive female goats is considered to be very low and estimated at 79%.

Table 16. Stage specific demographic rates used in calibrating goat flock projection matrix for the MRS goat production system

Stage class	Class age range in years	Stage duration in years (d_i)	Annual mortality rate (m_i)	Annual offtake rate (o_i)	Annual survivorship rate (s_i)	Annual fecundity rate(F)
Small flock size						
F_j	0–0.5	0.5	0.28	0.02	0.70	0.00
F_s	0.5–1.3	0.8	0.17	0.09	0.74	0.00
F_a	1.3–6.3	5	0.14	0.10	0.76	0.79
M_j	0–0.5	0.5	0.28	0.05	0.67	0.00
M_s	0.5–1.3	0.8	0.22	0.55	0.23	0.00
M_a	1.3–4.3	3	0.14	0.10	0.76	0.00

Stage-structured population projection matrices

The annual Lefkovitch stage-structured population projection matrix for agro-pastoral and pastoral goat flocks are given in Table 17. The population projection matrices are derived using the demographic rates given in Table 16.

Table 17. Lefkovitch stage-structured population projection matrices for the MRS goat flock

	Stage at year t					
Stage at year *t+1*	F_j	F_s	F_a	M_j	M_s	M_a
Small flock size						
F_j	0.00	0.00	0.60	0.00	0.00	0.00
F_s	0.70	0.39	0.00	0.00	0.00	0.00
F_a	0.00	0.35	0.76	0.00	0.00	0.00
M_j	0.00	0.00	0.60	0.00	0.00	0.00
M_s	0.00	0.00	0.00	0.67	0.12	0.00
M_a	0.00	0.00	0.00	0.00	0.11	0.76

Simulation of baseline goat flock growth dynamics

Goat flock growth rates, stable stage distributions and stage-specific reproductive values

The baseline stable stage distribution, stage-specific reproductive values and annual long-term goat population multiplication rate for MRS production system are given in Table 18. The projection of livestock numbers for different classes of goats in the MRS production system are given in Figure 6. It is observed that under the baseline scenario, the long-run goat multiplication rate for MRS production systems is 1.00, which implies a zero goat growth rate per year. The annual trend line for goat growth in MRS is almost flat, indicating zero growth rate.

Table 18. Baseline stable stage distribution (w), stage specific reproductive values (v) and annual long-term population multiplication rate for the MRS goat production system

Stage class	Parameter	
	W	V
F_j	0.17	1.00
F_s	0.19	1.43
F_a	0.28	2.50
M_j	0.17	0.00
M_s	0.13	0.00
M_a	0.06	0.00
Λ	1.0	

The stable stage distribution associated with this constant goat growth rate is 17%, 19%, 28%, 17%, 13%, and 6% for juvenile female, sub-adult female, adult female, juvenile male, sub-adult male and adult male goat, respectively. The stable stage distribution is dominated by female goats, especially adult females. It is also observed that the adult female contributes most to the goat reproductive value followed by sub-adult female. The reproductive value of male goat is assumed to be zero in this kind of goat growth modelling.

Sensitivity and elasticity analysis

The results of sensitivity and elasticity analyses for MRS production systems are given in Table 19. The results of elasticity analyses show that the long-term goat population growth rate is most elastic to the probability that an adult female survives and persists as an adult. In general, the adult female contributes more than 60% to the goat flock growth in the MRS production system. The annual population growth rate is second most elastic to the probability that sub-adult female survives and stays as a sub-adult. For example, a 1% increase in sub-adult survivorship of goats in the MRS production system results in about 24% increase in annual multiplication rate. In terms of stages of growth, it is also interesting to note that young female goats, sub-adult and adult stage contribute 15%, 24%, and 61%, respectively, to goat flock growth in the small flock MRS production system. Furthermore, it is also important to note that the female goat fertility contributes only 15%, while the annual survivorship contributes about 85% to the goat growth rate. Thus, similar to other goat production systems, under the baseline scenario, it is more important to reduce mortality rates than improving the fertility of goats to increase goat growth in the MRS production system. However, due to the small herd size, fertility management also deserves due attention.

Table 19. Sensitivity and elasticity matrices from Lefkovitch stage-structured population projection matrix for the MRS goat production system

	Sensitivity matrix			Elasticity matrix			
	F_j	F_s	F_a	F_j	F_s	F_a	Total
Stage class							
F_j	0.00	0.00	0.24	0.00	0.00	0.15	0.15
F_s	0.21	0.24	0.00	0.15	0.09	0.00	0.24
F_a	0.00	0.42	0.61	0.00	0.15	0.46	0.61
Total				0.15	0.24	0.61	1.00

Simulation of steady state goat flock growth dynamics

Stable stage distributions, stage-specific reproductive values and commercial offtake rates

The steady-state stable stage distribution, stage-specific reproductive values and commercial offtake rates for the MRS production system are given in Table 20. The steady state goat production is obtained by numerically adjusting the offtake rates by sex and stage of goat growth. This indicates that in order to obtain steady state goat production there is a need to decrease the goat flock size by decreasing certain types of goats which significantly contribute to goat growth. Thus, the zero goat growth rate is obtained by increasing the commercial offtake of female goats, mainly adult female goats. As a result, under steady state the percentage offtake of adult female goat substantially increased.

Table 20. Steady-state stable stage distribution (w), stage specific reproductive values (v) and offtake rates for the MRS production system

	Parameter		
Stage class	w	v	Offtake rate
F_j	0.16	1.00	0.02
F_s	0.20	1.31	0.10
F_a	0.27	2.16	0.17
M_j	0.16	0.00	0.05
M_s	0.13	0.00	0.55
M_a	0.07	0.00	0.10

Goat meat production

The annual steady state goat meat production (total carcass weight) for the MRS goat production system is given in Table 21. The average annual live offtake rate for the goat flock as a whole is 16%. The average annual meat production per goat flock is 7 kg, about one live goat equivalent. The baseline and steady state are similar and there is no need to adjust the number of adult female goats to obtain steady state.

Table 21. Steady state beef production and cumulative and annualized present value of gross margins by different goat production systems in Ethiopia[1]

Production system	Average net offtake rate (%)	Average annual goat meat production from the flock (Kg)[2]	Annualized present value of value added beef (ETB)	Annualized present value of beef per head of goat (ETB/ head)
MRS				
Medium flock size	0.16	7	793	132

Note: [1]The time horizon for the projection is 20 years.

[2]The annual beef production is in carcass equivalent weight assuming 45 to 50% dressing percentage.

Financial profitability of current goat production

The outputs from the goat production in the MRS production system are meat and manure. The results of the analysis of financial probability of goat meat production at steady state is given in Table 21. The annualized present value of *GM* for goat production per flock and per head are given in Table 21. The annualized present value of goat output per flock for MRS is estimated to be ETB793. On the other hand, the annualized present value of *GM* per head of goat is ETB132.

5.2 *Ex-ante* impact assessment of policy and investment interventions

Description of bio-economic simulation analysis

The baseline assessment of livestock sector in Ethiopia, based on parameters from the expert opinion, indicates that there is very high rate of mortality for the goats reared across the major livestock production systems. The causes of these high levels of mortality rates are hypothesized to be a high incidence of livestock diseases, including internal and external parasites, and inadequate animal feeding and management practices. The negative impact of livestock diseases and poor feeding management on household income, food security and the national economy is well-established.

First, for poor livestock producers, who subsist or survive on just a few animals as a source of food, income, means of production and main productive asset, the death of animals due to disease has a tremendous impact on their well-being. Second, livestock diseases also hinder the poor smallholder farmers from accessing and competing in domestic and global livestock and livestock product markets. Third, livestock mortality or productivity loss due to diseases or other factors, reduces the competitiveness of commercially-oriented livestock production through direct economic losses resulting from animal deaths and decreased productivity from morbidity associated with animal diseases and parasites, and inadequate management practices. Fourth, diseases affect the national economy by decreasing the foreign exchange earned from livestock exports since it limits access to international markets. Finally, important negative externalities of livestock disease include impacts on the health of other producers' livestock and on human health.

Given the fact that livestock mortality and morbidity are important causes of economic losses and food insecurity and poverty, appropriate animal health interventions are needed to reduce the negative impacts of livestock diseases and parasites on households and the national economy. The high incidence of disease and mortality indicates the lack of adequate investment in animal health and management practices. However, the funds available for various interventions are also limited which requires *ex-ante* assessments of the economic impacts, technical feasibility and cost-effectiveness of the proposed investment interventions to reduce livestock mortality due to livestock diseases and inadequate management practices. The bio-economic simulation analysis discussed in section 4 is applied to analyse *ex-ante* the impacts of combined animal health and feed management interventions in goat production in different production systems.

The combined investment interventions in animal health, feeding and management practices to reduce young stock and adult stock mortality was determined based on a serious of consultative discussions among the senior staff of the State Ministry of Livestock and the livestock master plan team. The suggested interventions involve changes in public and private sector veterinary service provisions and public investment. Accordingly, the combined investment interventions proposed to reduce young stock and adult stock mortality are improvements in access to and quality of veterinary health services through rationalizing public and private veterinary sector services, improvements in feeding and management practices (e.g. supplemental feeding practices like mineral supplements). The specific actions required are the: establishment of an enabling environment and road map for the rationalization of public and private sector tasks; setting up of a statutory body to regulate the veterinary profession; gradual decrease in subsidies given in public veterinary clinics (on services and drugs); and provision of incentives (credit and subsidies) for setting up private veterinary clinics in remote areas and by young veterinarians in all areas. The policy interventions are expected to result in the adoption of new technologies, such as the use of anti-parasitic control drugs and vaccinations for transboundary animal and other diseases.

It is assumed that under baseline scenario the animal population currently reached by veterinary health service is 30% and the percentage of the animal population at risk that are targeted by the interventions are 70% of the population. The adoption rate for interventions is assumed to progress slowly. The adoption rate is expected to reach 20% by the fifth year of the project; 40% by the tenth year; 80% by fiftieth year of the project; and is assumed to remain the same until the twentieth year of the project. The combined investment intervention is expected to result in the reduction in young stock mortality by 20% over the 20-year investment time horizon and in the reduction of older stock mortality by 10% over the same 20-year investment time horizon.

The initial investment cost of the intervention was estimated at ETB 1 billion to be equally spent over three years to improve animal health, feeding and management practices. The total investment cost was assumed to be secured from government sources. The intervention involves goats, camels, sheep and goats in the major livestock production systems (lowland grazing system, highland MRD system and MRS system). The annual recurrent costs associated with investment costs for individual livestock species are given in Table 22. The implementation of young stock immunization through vaccination against FMD for goat is assumed to cost ETB 10 /dose and two doses per head/year or ETB 20 per head/year is required.

Table 22. Assumptions on annual recurrent costs associated with investment costs to reduce young stock mortality (ETB/head)

Animal health intervention cost item	Costs (ETB/head)			
	Cattle	Camel	Sheep	Goats
Foot-and-mouth disease (FMD)	20	20	10	10
Costs of vaccines (package)	13	13	7	7
Anti-parasitic drugs (dipping or spraying)	14	14	6	6
Extension service (feed, housing, and sanitation)	1	1	0.5	0.5
Annual disease surveillance	1	1	0.5	0.5
Additional cost for improved veterinary service	4	3	1	1
Total annual recurrent costs (ETB/head)	53	52	25	25

The vaccination cost required for animal export diseases of trade, such as PPR, CBPP, CCPP, etc. is estimated at an unsubsidized cost of ETB13/head per year for goats. Goats will be also treated against internal and external parasites. The treatment against internal and external parasites is assumed to be ETB6/head for goat. The vaccination service charge is assumed to be ETB7/head on average. The additional cost for improved veterinary service per head is ETB1 for goats.

In addition to disease control and preventive measures, the investment intervention also involves livestock disease surveillance. The annual cost of implementing disease surveillance is estimated at ETB0.5/head for goats. The technical advisory support for livestock keepers to improve their livestock husbandry practices will be implemented through extension services. The additional annual extension services are estimated to cost ETB0.5/head for goats to achieve improved management in animal feeding, housing and better sanitation. The total investment cost per animal per year for vaccination and anti-parasitic drugs is estimated at ETB25/head for goat.

To realize the impact of animal health interventions, there also have to be complementary improvements in the animal feeding and management practices (discussed next). The adequate feeding of the pregnant animal at its late stage of pregnancy and early stage of lactation by providing more concentrates is suggested. This is assumed to cost about ETB3/kg for goats. The amount of concentrates recommended varies by classes of animals. First, in the case of goats it is recommended that a 0.5 kg concentrate provided to the dam for three months over two years. This is expected to increase milk yield by 1 kg and half of which (0.5 kg) goes to the kids and will result in incremental weight gain of 22 g/day. The remaining 0.5 kg of the milk is sold to increase the income for the goat keeper.

Results of the *ex-ante* impact assessment of policy and investment interventions

The potential productivity, output, income and cost effects of the suggested investment interventions in the goat sub-sector are analysed *ex ante* at different levels: at household or flock level, typology of livestock production zones level and national level. The *ex-ante* financial profitability of goat policy and investment interventions are based on 20-year projected incremental cash flows comparing *with* and *without* intervention scenarios following a partial budgeting approach as discussed in section 4. The *without* intervention scenario provides a counterfactual scenario against which to compare the impacts of policy and investment interventions in goat production. For this purpose, the household-level partial budgets and the building blocks for *ex ante* financial analysis were constructed for different flock sizes by different production systems and then the projected cash flows were derived in terms of incremental benefits; incremental costs; and incremental net benefits due to the project (investment interventions) only. The following sections present the results of the *ex-ante* assessment of policy and investment interventions in goat production in terms of financial profitability, impacts on future production–consumption balances and household-level income impacts.

Impacts on future production–consumption balance

The future impacts of policy and investment interventions in goat production is assessed *ex-ante* in terms of closing the rapidly growing production–consumption gap and generating surpluses of goat meat and milk products for export markets to generate foreign exchange earnings. This projection is also critical to anticipate the magnitude of required future strategies and investments in goat research and development (policies and technologies), which will be required to close the production–consumption gap in goat meat and milk production. Considering a 15-year projection period (2013–32), the results for goat meat and milk are presented in Tables 23 and 24, respectively.

Table 23. Projected national production, consumption, and production and consumption balance of goat meat with and without combined investment interventions in Ethiopia by year 2028

Status of intervention	National production	National consumption	Production–consumption balance (10^3 tonnes) +	Production as a percent of consumption (%)
	(10^3 tonnes)	(10^3 tonnes)		
Without	210	183	28	115
With	292	183	109	160

Note + negative values indicate deficits while positive values indicate surpluses. The beef is measured in terms of carcass equivalent of net live goat offtake.

Table 24. Projected national production, consumption, and production and consumption balances of goat milk 'with' and 'without' combined investment interventions in Ethiopia 2028

Status of intervention	National production	National consumption	Production-consumption balance (10^6 litres)+	Production as a percent of consumption (%)
	(10^6 litres)	(10^6 litres)		
'Without'	354	331	23	107
'With'	564	331	233	170

Note + negative values indicate deficits while positive values indicate surpluses.

Under the without intervention scenario, the projected total production of goat meat in 2028 is about 210 thousand metric tonnes. The projected total consumption of goat meat is estimated at 183 million metric tonnes so the domestic production will be sufficient to meet the projected consumption requirements. Thus, the projected self-sufficiency rate for goat meat in 2028 is about 115%. There will be a goat meat surplus of 28 thousand metric tonnes. Therefore, there is an opportunity to export surplus goat meat and thus generate foreign exchange earnings for the country. Investment intervention further expands goat meat production increasing the surplus goat meat to 109 thousand metric tonnes. So the challenge for goat meat is to find export markets which absorb the surplus created and to meet the required quality requirements at competitive prices.

The results of projections of the production and consumption of goat milk 'with' and 'without' investment interventions are presented in Table 24. Without investment intervention, the total goat milk production in 2028 is projected at about 354 million litres. As a whole, without investment intervention the self-sufficiency ratio in goat milk production is about 107 % (a surplus of 23 million litres). The combined policy and investment interventions resulted in further significant increase in the self-sufficiency ratio for goat milk from 107 to 170%. The challenge for goat milk is to find market especially to increase the domestic consumption of goat milk and goat dairy products.

Impacts on financial profitability

The results of the *ex-ante* financial profitability of the combined investment analyses by goat production systems in Ethiopia are given in Table 25. The *NPVs* are positive in all cases, all the *IRRs* are greater than the assumed discount rate of 10% and the *BCR* is also greater than 1 in all cases except for MRS. However, it is observed that the returns to livestock investment interventions differ by goat production systems. By far the highest *NPV* is observed for medium flock size pastoral production system (LG large), while the highest IRR is observed for small flock size MRD. In general, all the financial performance criteria used indicate the financial viability of combined goat policy and investment interventions by goat production systems in Ethiopia except for MRS. Investing in goat production in the MRS system is not financially profitable. It is important to note that there are also several social and cultural benefits of goats which are difficult to express in monetary terms and consequently not included in the analysis of financial profitability. As a result, the total benefit of goat production might be underestimated.

Table 25. Returns to combined policy and investment interventions in goat production by goat production systems in in Ethiopia (2013–32)

Goat production system	Flock size group	Indicators of return to investment*		
		NPV (ETB 10^6)	*IRR* (%)	*BCR*
MRS	Small	1161	21	0.95
MRD	Small	5309	404	7.88
	Medium	4956	44	3.18
LG	Small	7130	55	4.42
	Medium	3439	49	4.00
	Large	26713	68	7.63

Note: * Indicates that the investment analysis was made for 20 years assuming 10% discount rate (opportunity cost of capital).

Impacts on household income

In order to assess the household level income and poverty impacts of goat policy and investment interventions, the 20-years incremental benefits and costs from combined policy and investment interventions were annualized assuming a discount rate of 10%. The results are presented in Table 26. Five performance measures were derived: annual incremental benefits per flock, annual incremental costs per flock, annual net incremental benefits per flock, annual net incremental benefits per head of goat and annual net incremental per capita income. The annual incremental costs include both capital investment and recurrent costs. The size of annual incremental costs required indicates whether the investment or costs of investment interventions are within the reach of livestock keepers. The annual net incremental benefit is obtained as the difference between annual incremental benefits and annual incremental costs. The annual net incremental benefit per head of goat is obtained by dividing the annual incremental net benefit per flock by average goat flock size. This measures the productivity of goat in different production system. The annual net incremental per capita income is obtained by dividing the annual net incremental benefit per flock by average family size of 4.7 people. The results are presented by goat production systems and goat flock size classes.

Table 26. Summary of discounted benefits and costs due to combined investment interventions in goat production by production system in Ethiopia

Goat production system	Flock size group	Annual incremental benefits (ETB/ flock)	Annual incremental costs (ETB/ flock)	Annual incremental net benefit (ETB/ flock)	Annual net incremental benefit per head (ETB)	Annual net incremental per capita income (ETB)
MRS	Medium (5)*	231	243	-12	-2	-3
MRD	Small (3)	714	91	624	208	133
	Medium (13)	850	267	582	45	124
LG	Small (15)	1082	245	837	56	178
	Medium (9)	538	134	404	45	86
	Large (25)	3612	473	3139	126	668

Note: * The figures in parenthesis indicate the goat flock size.

The income impact of combined investment intervention in goat production is different by goat production systems and goat flock size classes. The highest incremental net benefit of ETB3139/flock is obtained for medium size pastoral goat flock followed by agro-pastoral goat flock. The income impact of investment in the MRS production system is negative. Within each production system also, it is observed that the higher the goat flock size the higher the incremental net benefit of investment intervention. This result indicates the importance of the production system in which goats are raised and the goat flock size in influencing the return to goat investment. The flock size indicates economies of scale in goat production, while the production system indicates the difference in productivity levels due to differences in costs of production and marketing, market infrastructure and access to markets. In general, the *ex-ante* assessment indicates that combined policy and investment interventions in goat production substantially enhances the returns to goat production under different production systems. It is also observed that larger goat flock sizes are more productive in all production systems and indicate the importance of economies of scale in raising goat productivity. In general, the *ex-ante* assessment indicates that combined policy and investment interventions in goat production substantially enhances the returns to goat production under different production systems.

6 Conclusions and policy recommendations

The objective of this paper is to present an analytical and empirical framework which integrates goat flock growth and economic models for simulating the impacts of improvements in goat production. The modelling framework allows for *ex-ante* assessment of technical and financial performance of goat production 'without' and 'with' investment interventions. The data on goat size and structure, demographic and financial parameters used in the bio-economic simulation model were obtained from secondary sources, based on literature review, opinions of national and international livestock experts and an analysis of cross-sectional household survey data from secondary sources.

The baseline assessment of goat production systems indicates that the goat sub-sector is characterized by high mortality rates, and low fertility and low offtake rates, thus contributing to a low productivity level. The average goat flock size observed is very small, particularly in the mixed crop livestock production systems. Bio-economic simulation of baseline situation indicates that the goat production in different production system is growing at annual growth rate of 2–4% except for the MRS which has a zero annual growth rate. The baseline assessment also indicates that adult female goats are the most important class of goats explaining the various future goat population growth trajectories.

The observed low flock size and level of productivity indicates the potential of increased returns from investing in goat genetic improvement, health, reproductive management and nutrition. Particularly, the results of sensitivity and elasticity analyses indicate that female goat fertility contributes only about 15%, while the annual survival of female goats contributes about 85% to the goat flock growth rate. Thus, it is more important to reduce mortality rate than improving the fertility of goats to increase goat flock growth in the different production systems. This indicates the importance of identifying the causes of goat mortality and implementing cost-effective measures to reduce it. The small flock size also indicates the need to increase flock size. Detailed *ex-ante* benefit–cost analysis of such interventions using the bio-economic simulation model outlined in this paper are required. Here, the bio-economic simulation model is applied to assess *ex-ante* the impacts of the proposed combined investment interventions to reduce young and adult stock mortality in goats.

The results of bio-economic simulation analysis indicate that the combined investment interventions in goat health, feeding and management practices to reduce goat young stock and adult stock mortality are financially viable in the MRD and LG systems, but not in the MRS. The investment enhances Ethiopia's goat meat and milk self-sufficiency ratio and has significant impact on goat keeper income. The implementation of the proposed combined investment interventions will require strong private and public partnerships and involve the rationalization and improvement of public and private sector veterinary service provisions and public investments. Some of the key policy recommendations include:

- Improvements in goat producers' access to quality feed at reasonable price;
- Improvements in goat extension and advisory services;
- Improvements in access to livestock markets and information;
- Improvements in access to financial services;
- Improvements in goat farm management practices;

- Improvements in access to and quality of veterinary health services through the rationalization of public and private veterinary sector services, and improvements in feeding and management practices;
- The establishment of an enabling environment and road map for the rationalization of public and private sector tasks;
- The establishment of a statutory body to regulate the veterinary profession;
- The gradual decrease in subsidies given in public veterinary clinics (on services and drugs); and
- The provision of incentives (credit and subsidies) for the establishment of private veterinary clinics in remote areas and by young veterinarians in all areas;
- The adoption of new technologies, such as the use of anti-parasitic control drugs and vaccinations for transboundary animal and other diseases;
- The rationalization of the role of the public and private sectors in animal health based on the nature of the goods. This should include:
    i. The preparation of a policy statement which clearly defines public and private tasks;
    ii. Full cost recovery by the public sector of private good tasks (such as clinical services) to avoid competition with the private sector;
    iii. The gradual withdrawal of the public sector from clinical services;
    iv. The establishment of sanitary mandate—the delegation of certain public good activities to the private sector; and
    v. The provision of loans for interested private service providers.

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