Preventive Veterinary Medicine 226 (2024) 106164

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Calculation of livestock biomass and value by province in Indonesia: Key information to support policymaking

Dominic Smith[a,g,*], Nyak Ilham[b,g], Riyandini Putri[c,g], Ermin Widjaja[d,g], Widagdo Sri Nugroho[e,g], Tarni Louisa Cooper[a,g], Harimurti Nuradji[c,g], Ni Luh Putu Indi Dharmayanti[c,g], Dianne Mayberry[f,g]

[a] *Griffith Asia Institute, Griffith University, Southbank Campus, Grey St., South Brisbane, Queensland 4101, Australia*
[b] *Research Centre for Behavioural and Circular Economics, Research Organization for Governance, Economy and Community Welfare, National Research and Innovation Agency Jalan Jend Gatot Subroto 10, Jakarta, Indonesia*
[c] *Research Centre for Veterinary Science, Research Organization for Health, National Research and Innovation Agency, KST Soekarno, Jl, Raya Jakarta-Bogor Km. 46, Cibinong, Bogor, West Java 16911, Indonesia*
[d] *Research Centre for Sustainable Production System and Life Cycle Assessment, Research Organization for Energy and Manufacturing, National Research and Innovation Agency. KST BJ Habibie, Jl. Raya Serpong, Appearance, Sub district Setu, South Tangerang City, Banten 15314, Indonesia*
[e] *Faculty of Veterinary Medicine, Universitas Gadjah Mada, Bulaksumur, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa, Yogyakarta 55281, Indonesia*
[f] *CSIRO Agriculture and Food, 306 Carmody Rd, St Lucia 4067, Australia*
[g] *Global Burden of Animal Diseases Programme*

ARTICLE INFO

Keywords:
Biomass
Herd dynamic model
Indonesia
Livestock value
Policymaking

ABSTRACT

Accurate estimations of the biomass and value of livestock in Indonesia are of great use in supporting investment decisions by the public and private sector and as a basis for estimating the losses due to animal disease.

Biomass and the partial direct use value for key livestock species (cattle, buffalo, sheep, goats, pigs, chickens) for all provinces of Indonesia were derived from secondary data using a novel spreadsheet-based model. Using beef cattle as an example, we also explored the use of a herd dynamics model to validate base data on populations and productivity used to generate biomass values, and these were found to be generally robust.

Total partial direct use value of livestock is estimated to be almost USD54 billion in 2021, comprising almost USD33 billion of population value and almost USD21 billion of production value. Beef cattle account for 44% of total value and chicken (broiler, layer and native chickens) account for a further 36% of the total.

Breaking the data down by province reveals the regional importance of some livestock types that are of relatively minor importance nationally (pigs in East Nusa Tenggara and sheep in West Java). It also reveals the importance of livestock in the poorest provinces of Indonesia, where livestock acts as a store of wealth and serves socio-cultural purposes.

1. Introduction

Livestock production is important to Indonesia, contributing to rural livelihoods, the supply of food of high nutritional value, and reducing reliance on imports of animals and their products. Across all provinces of Indonesia, a majority of the rural population keep at least one type of livestock. There are also significant commercial broiler and layer sectors in East and West Java as well as a large cattle feedlotting industry in Lampung and West Java based on fattening cattle from Australia and other countries, including Brazil. Demand for bovine meat is also partly met through imports of beef and Indian Buffalo Meat (Chang et al., 2020).

Livestock also play an important socio-cultural role in many parts of Indonesia; cattle, buffalo, sheep and goats are sacrificed on Eid al Adha (Sari and Adi, 2021), buffalo are used in traditional ceremonies in South Sulewesi (Sirajuddin et al., 2023), pigs in East Nusa Tenggara have cultural and social value (Deze and Pello, 2022; Leslie et al., 2015), sheep have historically had an important economic and religious role in

* Corresponding author at: Griffith Asia Institute, Griffith University, Southbank Campus, Grey St., South Brisbane, Queensland 4101, Australia.
E-mail addresses: dominic.smith@griffith.edu.au (D. Smith), nyak001@brin.go.id (N. Ilham), riyandini.putri@brin.go.id (R. Putri), ermi005@brin.go.id (E. Widjaja), weesnugroho@ugm.ac.id (W.S. Nugroho), tarni.cooper@griffith.edu.au (T.L. Cooper), harimurti.nuradji@brin.go.id (H. Nuradji), nilu011@brin.go.id (N.L.P.I. Dharmayanti), dianne.mayberry@csiro.au (D. Mayberry).

https://doi.org/10.1016/j.prevetmed.2024.106164
Received 10 September 2023; Received in revised form 28 February 2024; Accepted 1 March 2024
Available online 5 March 2024

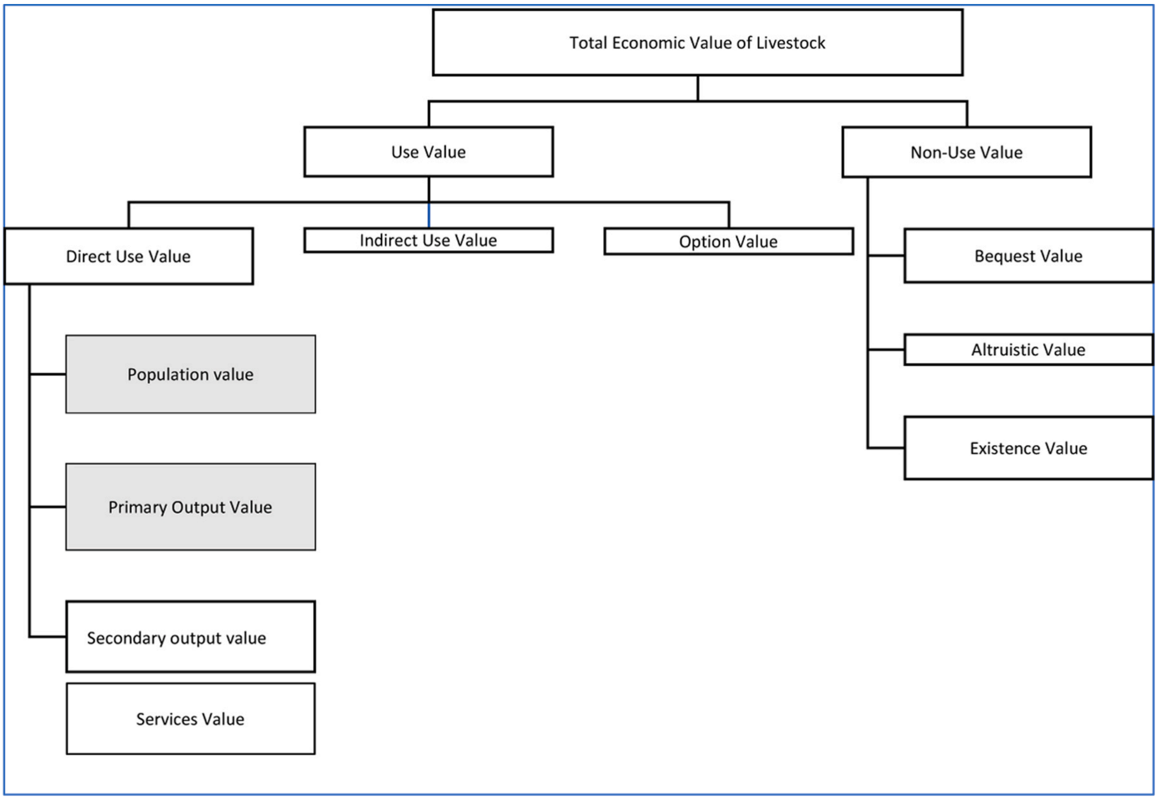

Fig. 1. Components of Economic Value of Livestock. Items included in the partial direct use value calculated in this paper are shaded in grey.

West Java (Hidayatuloh et al., 2019; Udo and Budisatria, 2011) and cattle racing is used to celebrate the rice harvest in Madura, East Java (Ilmiah and Widodo, 2022; Lutvaniyah et al., 2017; Nugahara et al., 2015; Sopana et al., 2023; Suprapto et al., 2022).

Acknowledging this widespread importance of livestock, the Indonesian government has prioritised livestock development with the inclusion of beef and buffalo meat, chicken meat, and chicken eggs on the list of key staple foods in the country (Ministry of Trade, 2021). Increases in livestock product availability including targets for increased beef production are included in the 2020–2024 Strategic Plan of the Ministry of Agriculture (Rafani and Sudaryanto, 2020).

In order for government to develop and implement effective policies for livestock production, animal health, and environmental protection, and for businesses to make informed investment decisions, accurate information on livestock biomass and livestock value is needed (Huntington et al., 2021). Combined measures of livestock biomass and human biomass can be also used to estimate potential environmental pressures in different geographic regions (Wolf, 2020).

Accurate measures of biomass and livestock value are also key to estimating the Animal Health Loss Envelope (Gilbert et al., 2023) as part of the overall process of estimating the burden of animal diseases (Jemberu et al., 2022; Rushton et al., 2021). These steps are an integral part of the framework of the Global Burden of Animal Diseases programme (https://animalhealthmetrics.org).

Despite the importance of livestock in Indonesia, there has not yet been an accurate estimation made of the biomass or total value of livestock. The aims of this paper are (i) to provide a first estimation of the biomass and value of key livestock types by province in Indonesia; (ii) to validate the key population data underlying these estimates using herd dynamic modelling; and (iii) to assess the sensitivity of biomass and livestock value estimations to stochastic variations of key input parameters.

The estimation of livestock value presented in this paper is based on the concept of Total Economic Value (Bateman et al., 2002). Fig. 1 shows the components of total economic value applied to the livestock sector as described by (Schrobback et al., 2023). Livestock value consists of two major parts – the use value and the non-use value. Non-use value includes the value of livestock as an asset to be passed to future generations (bequest value), the value to others of having livestock (altruistic value) and the value that occurs due to the continued existence of livestock (existence value). Use value of livestock includes: (i) value of direct use of livestock - this includes the value of the population, the value of primary outputs (e.g. meat, eggs, milk), secondary outputs (e.g. manure) and the value of draught power and other services; (ii) value of indirect use (e.g. cultural uses); and (iii) the value of the option of future use (e.g. value of genetics).

Source: Adapted from Bateman et al. (2002)

Data on indirect use, option, and non-use values of livestock in Indonesia is limited to isolated case studies (e.g. (Haq et al., 2019)) or non-existent. Similarly, data on services provided and the volume of secondary products produced are not reported at national scales or for all livestock. In this paper we therefore estimate the partial direct use value of livestock based on the population value of livestock and the value of major primary outputs of that livestock over a year. These are estimated for a range of livestock for each of the provinces of Indonesia.[1]

The key novel aspects of the research presented in the paper are: (i) one of the first estimations of biomass and livestock value at subnational level in a developing country; and (ii) the use of two step parameterization and projection herd dynamic modelling to validate underlying population levels and herd composition used in calculating biomass and livestock value.

[1] During the time period under analysis, Indonesia had 34 provinces. As of 2022, Indonesia has 38 provinces.

Table 1
Average Liveweight by Livestock Type.

Livestock Type	Standard average liveweight per head (kg)
Dairy Cattle	250
Buffalo	250
Pigs	70
Goats	20
Sheep	20
Broiler Chickens	1.5
Layer Chickens	1.5
Local Chickens	1.5

2. Materials and methods

Using a custom-developed spreadsheet model in Microsoft Excel (Microsoft, 2018), we calculated the biomass and partial direct use value of major livestock species and the biomass of humans in Indonesia from 2017 to 2021 at national and provincial levels based on national statistics data on populations and productivity. Because beef cattle make the largest contribution to livestock biomass and value, analysis of beef cattle biomass and value was further disaggregated by breed, sex, and age classes.

The validity of the population and herd structure figures underlying the calculation of beef cattle biomass and value was tested using a two-step parameterization and projection process in a herd dynamic model. The robustness of estimations of biomass and value was tested via a sensitivity analysis of the value of model output resulting from stochastic variations of key model inputs.

2.1. Data

Estimates of biomass and partial direct use value of livestock were based primarily on secondary data available from the Indonesian Bureau of Statistics and the Directorate General of Livestock and Animal Health. This is supplemented with data from publications based on recent beef cattle research projects in Indonesia. Annually updated data was used in most cases, but in some instances – for example for average liveweight per head, we had to apply the same values across multiple years as this is all that was available.

Population data by province for dairy cattle, buffalo, sheep, goats, broiler chicken, layer chicken, local chicken, pigs, and humans were sourced from Statistics Indonesia (Statistics Indonesia, 2018b, 2019b, 2020b, 2021b, 2022a). Beef cattle population information was available in more detail than for other livestock types and more accurate estimations of population were possible. Parameters relating to the proportion of population of beef cattle by breed, sex and age group in each province were sourced from the national survey of beef cattle and buffalo conducted in 2011 (Statistics Indonesia, 2011). These parameters were combined with provincial cattle population figures for each year to give an estimate of the population disaggregated by breed, age, and sex for each province.

Average liveweights for all livestock types except beef cattle were assumed to be the same as the standard liveweight per head used for calculations of livestock price statistics in Indonesia (Statistics Indonesia, 2021a), and the same values are used for each year of our analysis (Table 1). Average per capita weight of humans was taken from (Walpole et al., 2012).

There are substantial differences in the average liveweight of different beef cattle breeds within Indonesia. For this reason, and because population data was also available for different breeds and classes of beef cattle, estimates of beef cattle weights for different breeds and sex and age categories were obtained from the literature (Table 2). Estimates for Bali and Madura cattle weights were based on the field surveys of Latulumamina (2013) and Prihandini et al., (2020), respectively. Ongole cattle weight estimation by sex and age is based research station (Adinata et al., 2022) and on-farm data (Antari et al., 2014; Mayberry et al., 2014) in East Java. There was insufficient information available on what breeds were included in 'other cattle', and liveweight data of Ongole cattle were applied. As was the case for other livestock species, the same values were applied across each year of the analysis.

Output data was collated for animals slaughtered, milk production and egg production. The number and slaughter weight of beef cattle, cull cow, buffalo, pigs, goats, and sheep slaughtered by province are sourced from Statistics Indonesia annual publications (Statistics Indonesia, 2017b, 2018e, 2019d, 2020d, 2021d). Culled cows could be either beef or dairy cattle breeds, but the data do not acknowledge this distinction. For the purpose of this analysis, we assume that the proportion of cull cows that come from dairy cattle are the same as the proportion of dairy cattle within the overall cattle population within each province.

For beef cattle, buffalo, pigs, goats and sheep, the number of animals slaughtered is reported for both within and outside slaughterhouses. Sheep slaughter weights are not reported but were assumed to be the same as for goats within the same province (see for example the use of identical sheep and goat weights by age in studies such as Budisatria et al. 2010). Milk output by province was obtained from statistical yearbooks (Statistics Indonesia, 2018d, 2019c, 2020c, 2021c, 2022b). Egg production by province from layer chickens and local chickens is given in the annual publication "Livestock in Figures" (Statistics Indonesia, 2018b, 2019b, 2020b, 2021b, 2022a).

Average monthly farmgate livestock prices per head for cattle, buffalo, pigs, goats, and chickens for all provinces were sourced from Statistics Indonesia (Statistics Indonesia, 2017a, 2018a, 2019a, 2020a, 2021a). Price per head of sheep in each province is not reported and was assumed to be the same as the price per head of goats in the same province. Prices per kilogram of liveweight for all livestock types were derived by dividing the per head prices by the standard weights shown in Table 1.

Per kilogram farmgate prices for slaughter cattle, cull cows, slaughter buffalo, slaughter goats, slaughter sheep and slaughter pigs are assumed to be the same as the per kilogram average prices for each livestock type. While there may be differences in the actual farmgate per kilogram prices of different classes of livestock (for example cull cows vs slaughter cattle) these differences are assumed to be accurately captured in the process of deriving an average per kilogram price for each livestock type.

Price of milk per litre was obtained from unpublished data from the

Table 2
Sub-categories of beef cattle population and average liveweight (kg) at different ages by breed used for beef cattle biomass calculation.

	Male			Female				
	Calf	Young	Adult	Calf	Young	Adult		
						2–4 years	4–6 years	>6 years
Bali Cattle	160	187	281	100	214	229	251	265
Madura Cattle	122	192	306	121	190	282	282	282
Ongole Cattle	200	284	450	197	250	315	387	387
Other Cattle	200	284	450	197	250	315	387	387

Table 3
Livestock Types and Key Outputs Included in Value Calculations.

Livestock Type	Outputs
Beef Cattle	Slaughter Cattle, Cull Cows
Dairy Cattle	Milk, Cull Cows
Buffalo	Buffalo for Slaughter
Pigs	Pigs for Slaughter
Layers	Eggs
Broilers	Broilers
Local Chickens	Eggs
Sheep	Sheep for Slaughter
Goats	Goats for Slaughter

Directorate General of Livestock and Animal Health Services. Farmgate price of layer eggs per kg and native chicken eggs per 10 eggs are available from Statistics Indonesia (Statistics Indonesia, 2017a, 2018a, 2019a, 2020a, 2021a).

Inflation data (CPI change) to derive a composite index for inflation from 2017 to 2021 for Indonesia was obtained from the annual statistical yearbooks of 2022 and 2019 (Statistics Indonesia, 2019c, 2022b). Gross Provincial Domestic Product (GPDP) figures were obtained from the Annual Statistical Yearbook of 2022 (Statistics Indonesia, 2021c)

2.2. Validation of Statistics Indonesia population data using herd dynamic model

The limitations of livestock surveys and censuses mean that population data reported in national statistics may not always be accurate (e.g.,(Fordyce et al., 2013). As our spreadsheet model is based on the use of national statistics, herd dynamic modelling was used to validate some of the key parameters related to beef cattle population and herd structure that are used to calculate biomass and livestock value. The DYNMOD herd dynamic model (Lesnoff, 2013) was used to cross-check the reliability of herd growth, slaughter numbers, herd structure and overall population for reported for beef cattle by Statistics Indonesia.

The validation was done as a two-step process. First, a set of parameters for 2018 from Statistics Indonesia (average carcass weight, overall population, average age at slaughter by sex) were combined with estimations of unknown parameters (mortality rates by age and sex, parturition rates were initially seeded with the default values for cattle from DYNMOD). These unknown parameters were then progressively re-estimated and used as inputs to the STEADY1 module of DYNMOD to over a series of re-estimations to generate a herd structure that would broadly align with the Statistics Indonesia reported offtake figures for 2018. This generated a herd structure from the 2018 cattle population, slaughter cattle numbers and a set of fertility and mortality parameters. The first check of the reliability of the Statistics Indonesia figures is to examine the herd structure and parameters of the final estimated version of the STEADY1 module. If the herd structure and parameters that are needed to generate an approximation of the Statistics Indonesia offtake levels are within a biologically feasible range for the breed and production system (falling within a range of values reported in a recent review of livestock mortality indicators (Wong et al., 2021) and recent studies on tropical and sub-tropical cattle production systems, (including Yitagesu et al. 2022 Budisatria et al. 2021 and Baco et al. 2019) then we can infer some level of reliability of the Statistics Indonesia figures.

Second, the PROJ herd growth module of DYNMOD was used to check the robustness of the parameters generated by the first step. The model was calibrated with the 2018 herd size (Statistics Indonesia, 2019c) as the base and the parameters from the first step were used to calculate herd growth, herd structure, turnoff numbers and liveweight slaughter figures until 2021. The generated figures from the herd dynamic model for 2021 were then checked against the Statistics Indonesia figures for the same year to see if there was any consistency. If the parameters from step 1 fall within the feasible values range defined above and the generated population and turn-off figures for a number of years are consistent between the PROJ module and the figures from Statistics Indonesia then we can further infer some level of reliability and inter-temporal consistency in the Statistics Indonesia figures.

2.3. Calculating biomass and the partial direct use value of livestock

The biomass of dairy cattle, buffalo, sheep, goats, pigs, chickens, and humans in each province is calculated by multiplying the annual population of each species in a province by the average liveweight. Building on approaches described in Li et al. (2023), the biomass of beef cattle in each province is calculated by multiplying the population of cattle in each subcategory (breed, age, sex) by the estimate of average liveweight per head of cattle in that sub-category. For all species, national biomass is estimated by summing provincial biomass estimates.

Similar to the calculations used by Jemberu et al. (2022) in the Global Burden of Animal Diseases case study in Ethiopia, the partial direct use value of livestock was calculated as the sum of the value of the population of each species and the value of outputs produced (see Table 3).

The population value of each livestock population was calculated by multiplying the biomass of the population by the average price per head and divided by the average liveweight per head. This calculation was done for each province and summed to provide a national estimate.

For beef cattle, buffalo, pigs, goats and sheep, the number of animals slaughtered in slaughterhouses counted as outputs in each province are calculated by taking the total reported numbers of slaughterhouse slaughtered animals, adding the number of slaughter animals sent outside the province for slaughter and subtracting the number of slaughter animals from other provinces slaughtered in the province. This calculation was done separately for each species, with the process described in Eqs. (1) to (5).

$$V_{sl} = PopV_{sl} + ProdV_{sl} \tag{1}$$

$$PopV_{sl} = \left(Bio_{sl} * \left(\frac{\Pr_{sl}}{W_{sl}} \right) \right) \tag{2}$$

$$Bio_{sl} = Pop_{sl} * W_{sl} \tag{3}$$

$$Bio_{bl} = Pop_{Tbl,Abl} * W_{Tbl,Abl} (\text{beef cattle only}) \tag{4}$$

$$ProdV_{sl} = \left((Sls_{sl} + Slo_{sl}) * \left(\left(\frac{\Pr_{sl}}{W_{sl}} \right) * Slw_{sl} \right) \right) \tag{5}$$

Where: V_{sl} = *Partial Direct Use Value of species s in Province l* $PopV_{sl}$ = *Population Value of species s in Province l* $ProdV_{sl}$ = *Farmgate Production Value of species s in Province l* Bio_{sl} = *Biomass of species s in Province l* (Except beef cattle) Pop_{sl} = *Population of species s in Province l* W_{sl} = *Average weight of Species s in province l* Bio_{bl} = *Biomass of beef cattle in Province l* $Pop_{Tbl,Abl}$ = *Population of cattle by breed and Age group in Province l* $W_{Tbl,Abl}$ = *Average weight of cattle by breed and age group in province l* $\Pr_{sl}$ = *average price of species s per head in province l* Sls_{sl} = *number of head of species s slaughtered in slaughterhouses in province l* Slo_{sl} = *number of head of species s slaughtered outside slaughterhouses in province l* Slw_{sl} = *Average slaughterweight of species s in province l* l= provinces of Indonesia (1……34) Tb = breeds of beef cattle (Bali, Onggole, Madura,Other) Ab = Age group of beef cattle (male calf, male young, male adult, female calf, female young, female 2–4 years, female 4–6 years, female over 6 years)

The partial direct use value of dairy cattle in a province in each year is calculated as the sum of the value of the dairy cattle population in the province and the value of the outputs produced by that dairy cattle population (milk and cull cows). The value of milk production is calculated by multiplying the quantity of milk in litres produced per province by the average farmgate price per litre of milk. Cull cow value

Table 4
Differences between Official and PROJ module generated population and offtake figures 2018–2021.

	Population (heads)			Offtake (heads)		
	Statistics Indonesia	PROJ module generated	% difference	Statistics Indonesia	PROJ module generated	% difference
2018	16,432,945	16,432,945	BASE YEAR	1380,203	1380,203	BASE YEAR
2019	16,930,025	17,253,501	1.9%	1357,774	1137,099.00	-16.3%
2020	17,440,393	17,900,633	2.6%	1592,920	1302,567.00	-18.2%
2021	17,977,214	18,374,866	2.2%	1547,062	1412,094.40	-8.7%

Reported data from (Statistics Indonesia, 2018e, 2019d, 2020d, 2021d, 2022a)

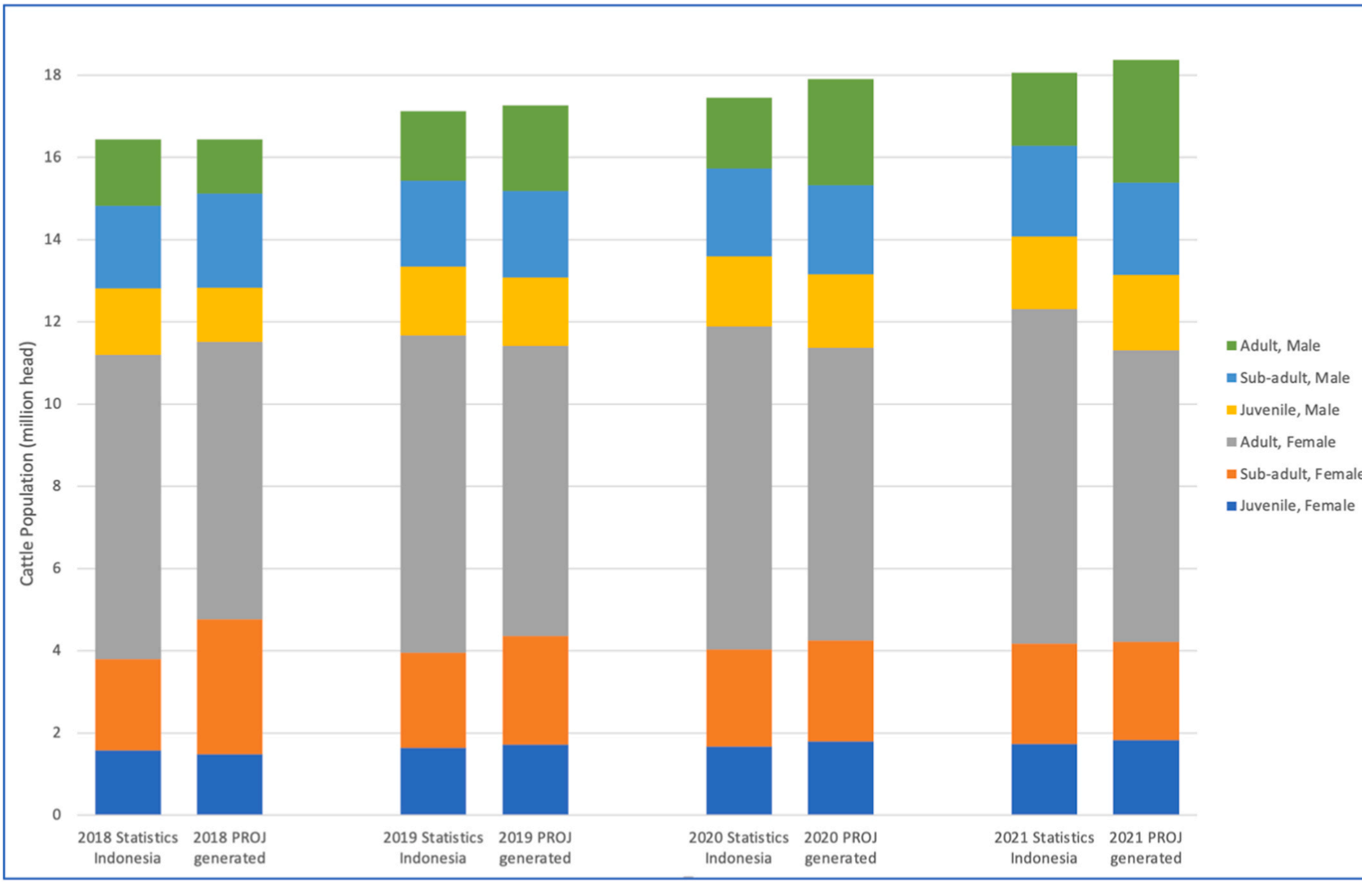

Fig. 2. Herd structure generated by PROJ module compared to Statistics Indonesia reported herd structure 2018–2021.

is calculated by multiplying the number of cull cows slaughtered by province by the average slaughter weight in kg (Statistics Indonesia, 2021d) and the average price per kg for cattle in the province (Statistics Indonesia, 2021a).

As the production cycle of commercial broiler chickens are much less than one year, the partial direct use value of broiler chickens within a province for a year is calculated by multiplying the total number of broilers in all cycles over the year by the average weight per head and the average price per kg for chickens in the province (Statistics Indonesia, 2021a).

The partial direct use value of commercial layer chickens and native chickens (defined as local breed multipurpose chicken) in a province in each year is calculated as the sum of the value of the commercial layer chicken population and the native chicken population in the province and the value of the outputs produced by that population - eggs. Egg value is calculated by multiplying the number of kilograms of eggs (for commercial chickens) or number of eggs (for village chickens) (Statistics Indonesia, 2022b) produced per province by the average price per kg or per egg in the province (Statistics Indonesia, 2021a).

2.4. Sensitivity analysis

The calculated biomass figures and the calculated partial direct use value of livestock in 2021 are based on the interaction of numerous input parameters, including livestock population levels, weights of various livestock types, and prices of animals and outputs.

We developed a custom sensitivity analysis model implemented in Microsoft Excel to perform two categories of sensitivity analysis. The first category is an estimation of the probability distribution of output values derived from simultaneous variations of key input parameters following a triangular distribution (Fairchild et al., 2016). Key characteristics of the triangular distribution can be seen in Eqs. (6), (7), and (8).

$$mean = \left(\frac{a+b+c}{3}\right) \tag{6}$$

$$variance = \left(\frac{a^2+b^2+c^2-ab-ac-bc}{18}\right) \tag{7}$$

And the cumulative distribution function is:

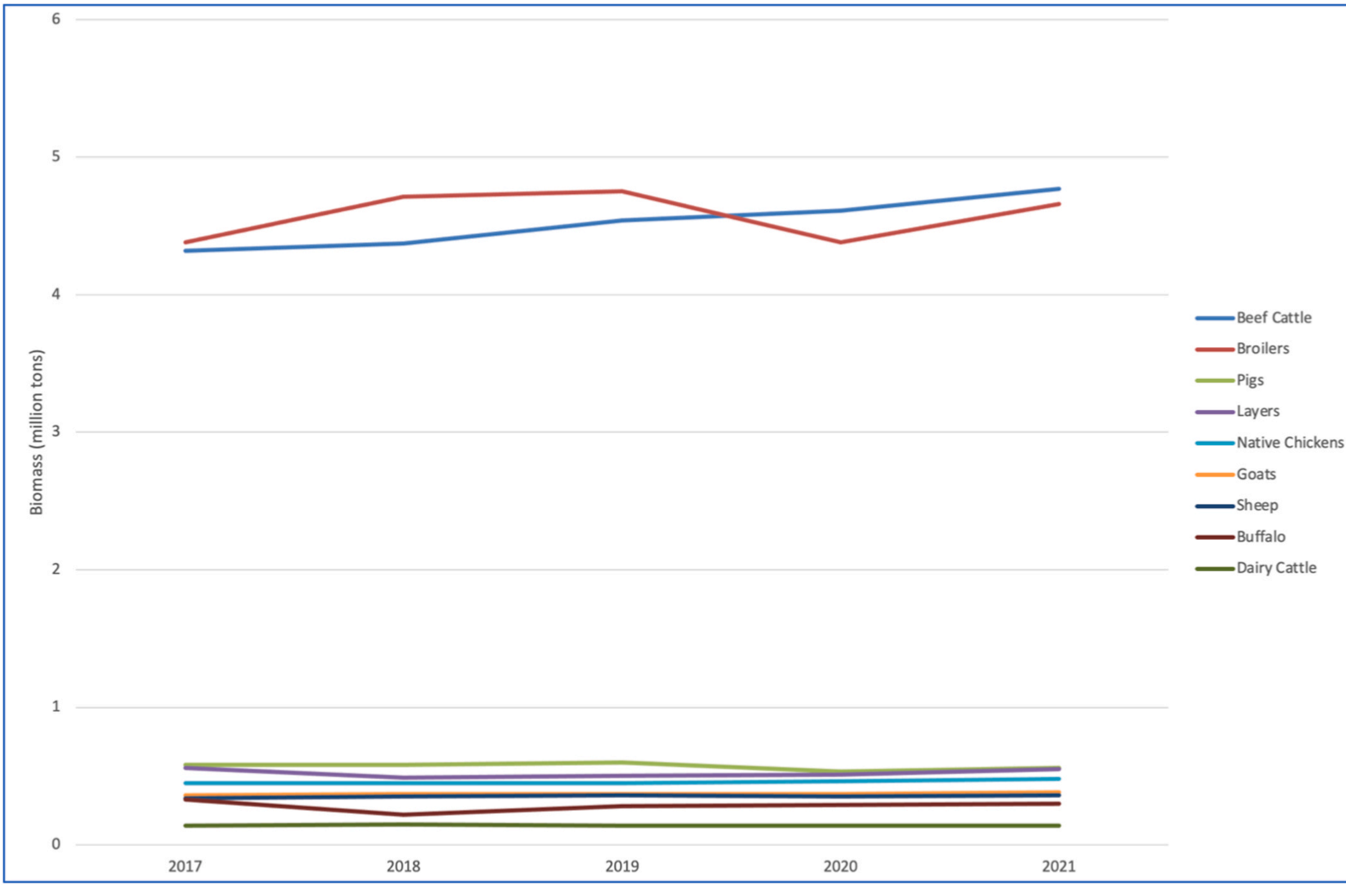

Fig. 3. Livestock biomass by livestock type in Indonesia 2017–2021.

$$F(x|a,b,c) = \begin{cases} 0, x < a \\ \frac{(x-a)^2}{(c-a)(b-a)}, a \le x \le b \\ 1 - \frac{(c-x)^2}{(c-a)(c-b)}, b < x \le c \\ 1, x > c \end{cases} \quad (8)$$

Where:a = lower limit of distributionb = peak value of distribution; andc = upper limit of distributionx = the value of the variable with a triangular distribution

A distribution of total livestock biomass was estimated using 10,000 iterations of a Monte-Carlo simulation (Doubilet et al., 1985). A set of input parameters (cattle weight, buffalo weight, chicken weight, goat weight and sheep weight) were simultaneously varied based on triangular distributions where the peak value for each parameter was set as the value used for the main calculation of biomass and the lowest value and highest value were set as 20% below peak value and 20% above peak value respectively. The actual variability of key input parameters is not known, so a nominal figure of 20% was used in order to gauge the relative variability of inputs and outputs.

The same technique was used to estimate the distribution of the partial direct use value of livestock by varying livestock price parameters (cattle price, buffalo price, chicken price, goat price and sheep price) and output price parameters (egg price, milk price).

The second category of sensitivity analysis performed on the biomass and livestock value calculations was to vary single input values by +/- 20% following a triangular distribution while holding all other input values at their mean level. Sequentially performing this analysis for each key input values enables the estimation of the relative impacts of each key input on the distribution of output values.

3. Results

3.1. Validation of Statistics Indonesia population data using herd dynamic model

Using the reported 2018 cattle population (Statistics Indonesia, 2019c) as an input to the STEADY1 module, an iterative approach was used to arrive at a set of mortality and fertility parameters that would generate a cattle offtake figure comparable to the Statistics Indonesia figures for cattle offtake in 2018 (Statistics Indonesia, 2019d). The fertility and mortality parameters are summarised in the supplementary section and are well within a feasible range for a tropical intensive and semi-intensive production system. This implies a level of reliability of the official figures.

The estimated total population levels generated by the PROJ module of the herd dynamic model for the years 2019–2021 were only around 2 percent larger than the figures from Statistics Indonesia (Table 4). This implies that the age structure, fertility, and mortality parameter values generated in the STEADY1 module of the herd structure model are able to be used to generate a total herd growth simulation over the 2018–2021 period that is consistent with the Statistics Indonesia population figures. The PROJ module prediction of offtake quantities in 2021 is less consistent with the official figures, with an estimate of 1412,094 head – around 8.7% lower than that reported by Statistics Indonesia.

The difference in offtake levels may be due to slaughter figures from

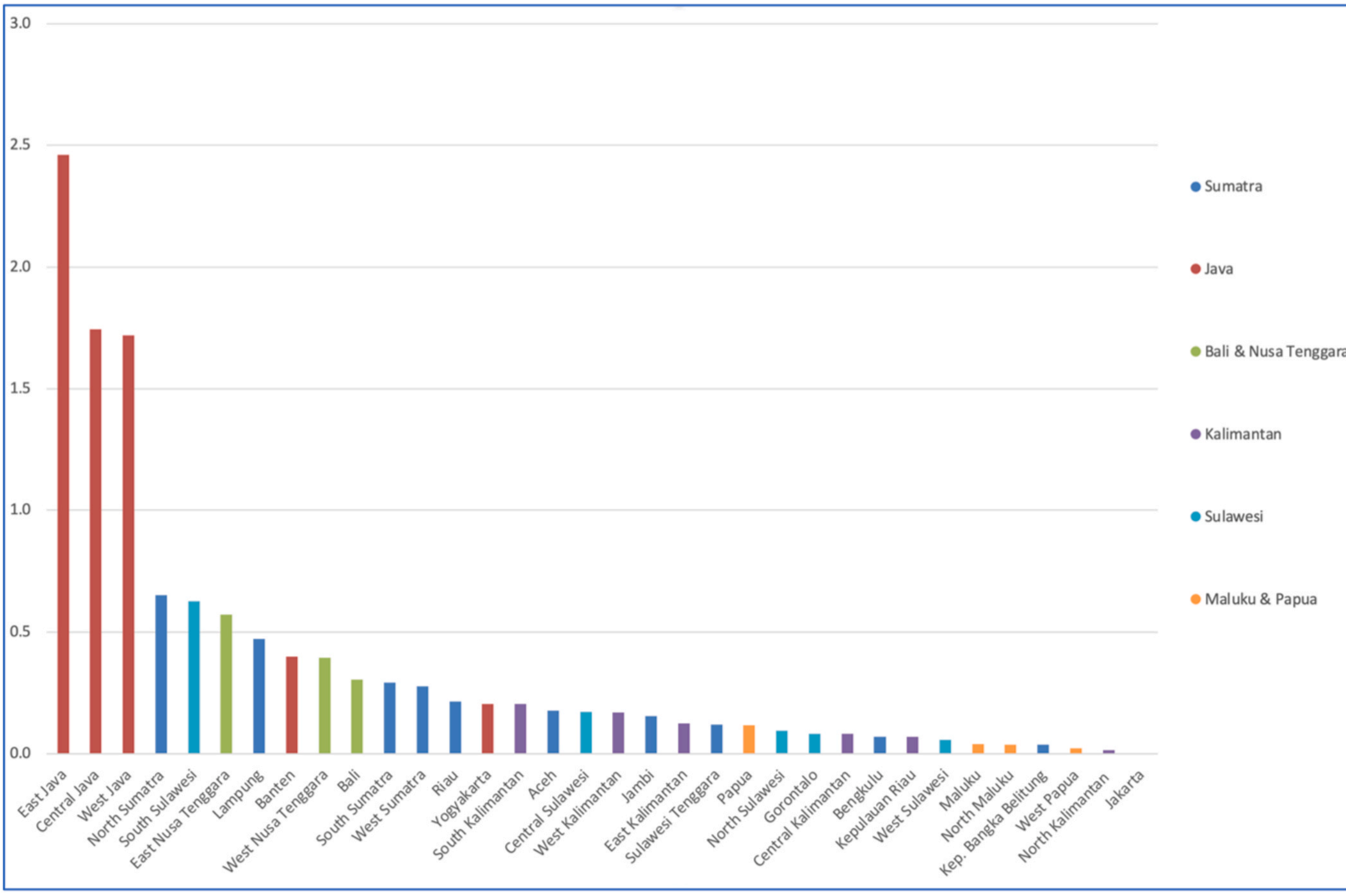

Fig. 4. Total livestock Biomass (million Tons) by province 2021.

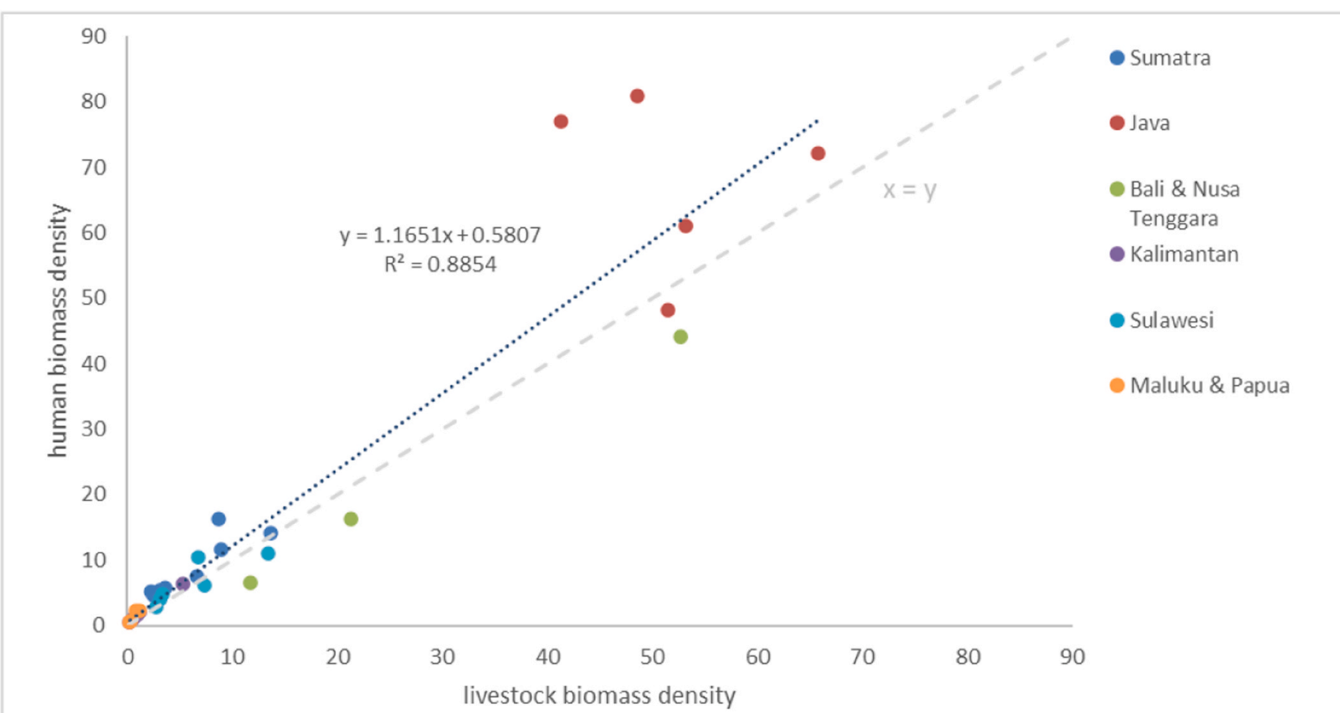

Fig. 5. Correlation between livestock and human biomass density (t liveweight / km2) across Indonesian provinces. Jakarta is not included in this figure due to the very high human population biomass.

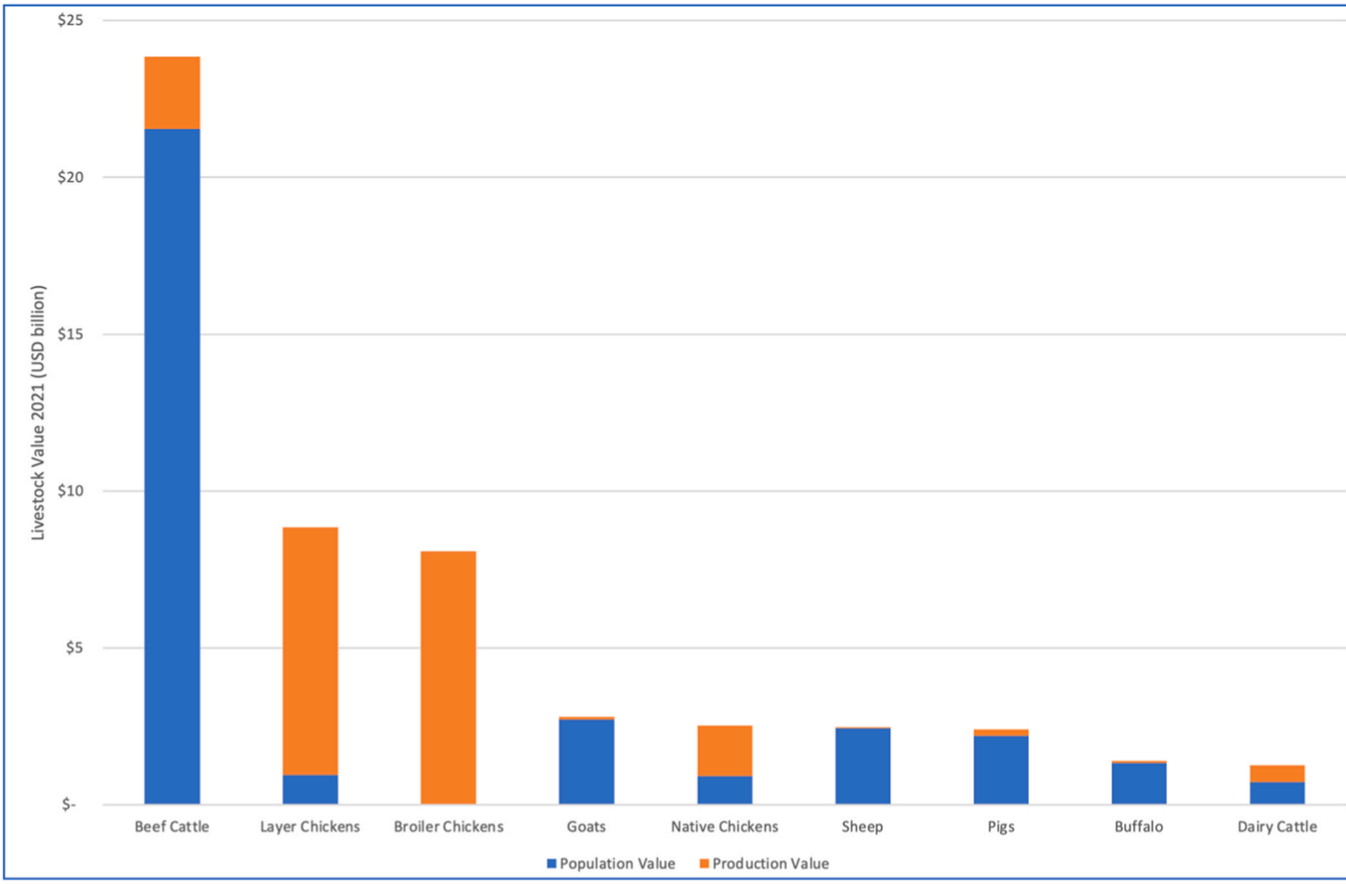

Fig. 6. Livestock Population and Production Value in Indonesia by livestock type 2021 (USD billion).

Statistics Indonesia including imported slaughter cattle in addition to Indonesian born cattle while the PROJ module is generating based on offtake from the Indonesian herd only. The variation may also be due to the fact that slaughter numbers generally are more variable than population numbers as offtake levels are dependent on many different factors, rather than just on bio-physical parameters.

Table 3 shows differences in population structure between herd structures generated by the PROJ module and the reported herd structure from Statistics Indonesia. The generated structure tends to overestimate the number of adult males and underestimate the number of adult females (see Fig. 2).

The fertility and mortality parameters generated by the STEADY1 module are within a feasible range for Indonesia and those parameters can be used to generate a consistent population growth trajectory for the cattle herd. While there are differences in the offtake figures generated by STEADY1 module and the reported figures and some differences in generated herd structure these are relatively minor compared to the total biomass and livestock partial value levels. Therefore we conclude that it is reasonable to use the Statistics Indonesia figures as inputs to our novel spreadsheet model and as a basis for calculating biomass and livestock partial use value.

3.2. Biomass

Overall livestock biomass in 2021 was estimated at 12.2 million tons. This is just over 77% of the estimated human biomass in Indonesia of 15.8 million tons in the same year and represents an increase from 11.5 million tons in 2017. The increase in total livestock biomass was driven mainly by an increase in the beef cattle population, from 16.43 million to 18.05 million animals (Fig. 2 and Table 3 in Supplementary Materials). There was little variation in biomass of local chickens (0.46 $\pm$ 0.013 million tons (mean $\pm$ SD), goats (0.37 $\pm$ 0.007), sheep (0.35 $\pm$ 0.008) and dairy cattle (0.14 $\pm$ 0.004), but there were decreases in the biomass of broilers, buffalo, pigs, and commercial layer associated with specific events.

Total national livestock biomass is dominated by beef cattle[2] and broiler chickens, which contributed on average 38% and 39% of the total biomass, respectively between 2017 and 2021. The remaining livestock types combined contribute an average of 23% of total biomass (Fig. 3).

Geographically, livestock biomass is concentrated in Java, with East Java, Central Java and West Java together accounting for almost 50% of the total livestock biomass of Indonesia (Fig. 4). East Java has the largest population of beef cattle and West Java has the largest population of broilers.

The livestock biomass per square kilometre for Indonesia in 2021 is 6.37 tons. This figure varies significantly between provinces, with Bali and the densely populated provinces of Java each having more than 40 tons of livestock biomass per square kilometre and the less densely populated provinces in Kalimantan, Maluku and Papua having biomass figures of less than 1 ton per square kilometre.

The strong positive correlation between provincial levels of livestock biomass and human biomass (Fig. 4) reflects the dominance of smallholder production systems and the concentration of livestock in more densely human populated provinces. Livestock biomass is greater that

[2] It is worth noting that the biomass calculated for beef cattle in 2021 (around 4.768 million tons) using our detailed method is only around 6 percent greater than a biomass estimate for beef cattle using a simple calculation of population x 250 kg/head -the average value used by Statistics Indonesia (Statistics Indonesia. 2018e. *Statistics of Livestock Slaughtered*. Badan Pusat Statistik.).

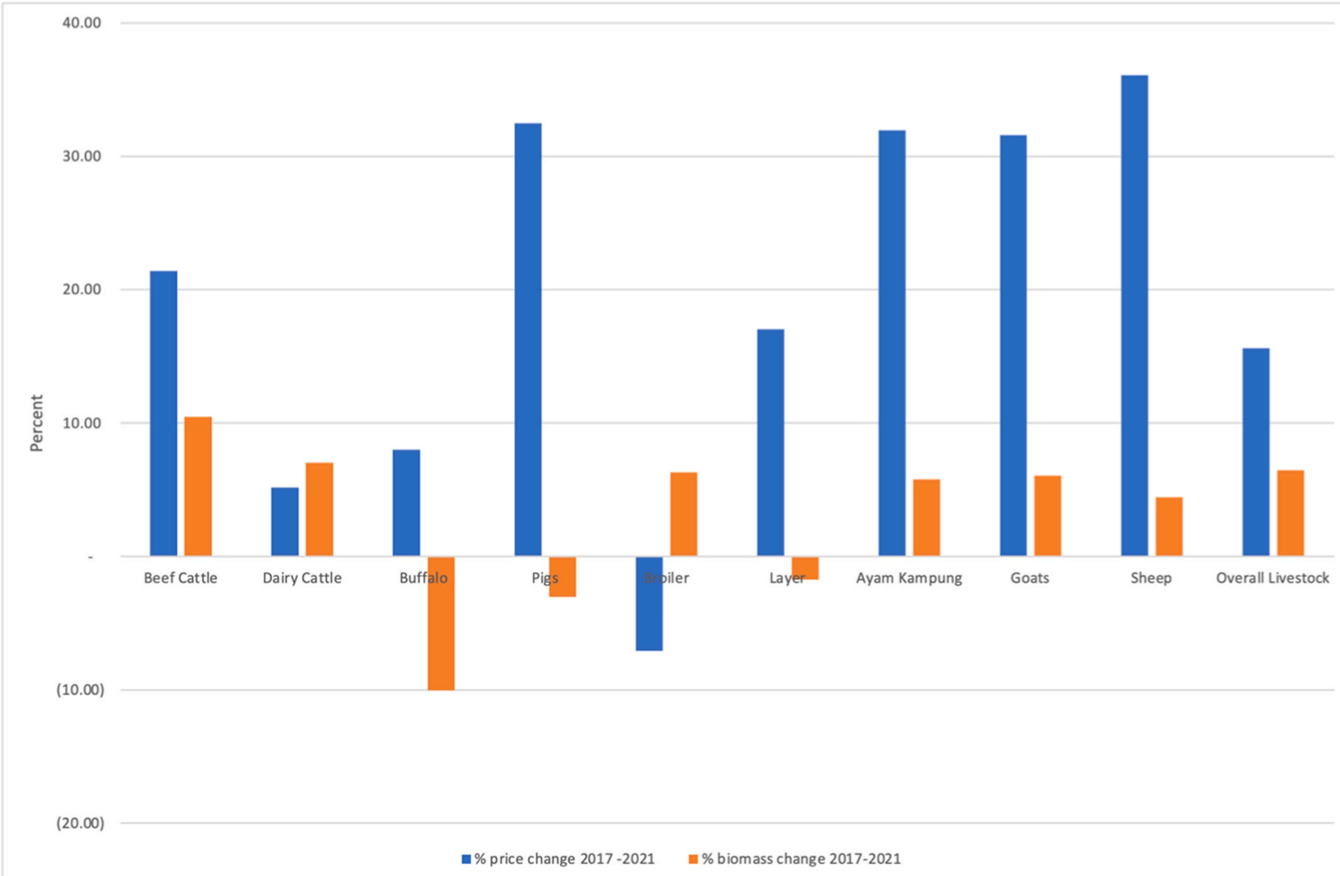

Fig. 7. Percentage change of livestock partial direct use value due to price change and biomass change 2017–2021.

human biomass in East Java, Bali, Nusa Tenggara, South Sulawesi and Gorontolo. Livestock biomass is almost twice that of human biomass in East Nusa Tenggara. Fig 5

3.3. Partial direct use value of livestock

The partial direct use value of livestock was USD 52.19 billion[3] in 2021 and has increased by 22% from USD 42.75 billion in 2017 (Table 3). This increase was driven by an increase in the partial direct use value of beef cattle (from USD 17.59 billion to USD 23.19 billion). Similar to biomass, the partial direct use value of livestock was dominated by beef cattle. However, the relative contribution of broilers was smaller, contributing 15% of partial direct use value in 2021.

Cattle have huge population value, but productivity (output value per asset value) is relatively low. In comparison, the productivity of poultry is high, with a relatively low value of population producing a large value of outputs per year (Fig. 6).

Changes in the partial direct use value of livestock between 2017 and 2021 can be attributed to changes in biomass and unit prices of livestock (in constant 2017 USD). As shown in Fig. 7, for most livestock types, both the change in biomass and the change in prices were positive between 2017 and 2021. Price changes had a larger impact on value change between 2017 and 2021 than biomass change for almost all livestock types, except for dairy cattle and broiler chickens.

The partial direct use value of livestock in 2021 by province varies between USD17 million in Jakarta (official statistics report very low numbers of livestock in the capital region) and more than USD13.3 billion (in East Java) (Fig. 8a). Livestock value is significantly concentrated on the island of Java, which accounts for USD29.2 billion of livestock value in 2021 (54% of total value). This reflects the high levels of livestock biomass in most provinces of Java.

Per capita partial direct use livestock value is highest in the province of East Nusa Tenggara at a value of almost USD360 per person in 2021 (Fig. 8b). The high per capita value of livestock in the province reflects the importance of cattle and pigs as stores of household wealth.

The relative importance of the livestock sector to the overall economy of a province can be estimated by comparing the partial direct use value of livestock to the Gross Provincial Domestic Product (GPDP) – an example for Nepal is given in (Rushton, 2009). This figure is highest in the province of East Nusa Tenggara (Fig. 8d), where the partial direct use value of livestock is equivalent to 25% of the GPDP. This reflects the widespread holdings of cattle and pigs by households and that the GPDP of East Nusa Tenggara is relatively low.

3.4. Sensitivity analysis

The distribution of biomass and partial direct use values generated by the stochastic estimation of key input parameters fits a normal distribution as determined by graphical interpretation and by using the Kolmogorov–Smirnov test (Mishra et al., 2019) (Table 5).

The sensitivity of total livestock biomass to a +/- 20% variation of different input parameters is shown in Fig. 9a. Given the dominance of chicken and cattle in the overall level of biomass, it is not surprising that the partial direct use value of livestock is most sensitive to changes in the average weight of cattle and the average weight of chickens used in the calculations. A 20% variation in the average weight of chickens will cause the overall biomass to vary by 9.3% and the same variation for cattle weights causes an 8.1% change in biomass. Table 6

[3] The figures reported here are calculated on the basis of constant 2017 USD, deflated by Indonesian CPI increases.

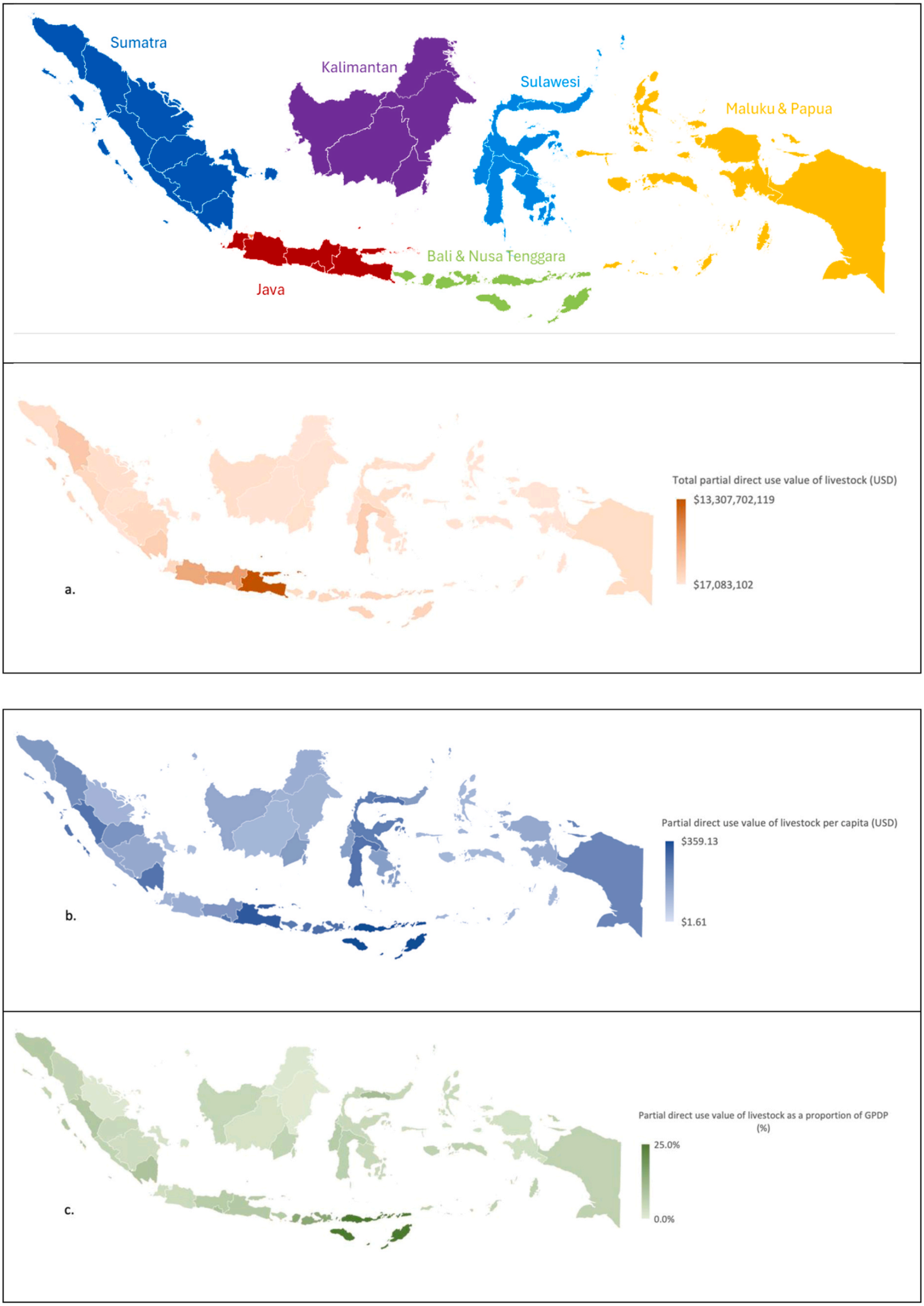

Fig. 8. Distribution of Partial Total Direct Use Value of livestock Across Indonesia (2021) a) Map of Indonesia indicating key regions described in this analysis, b) total partial direct use value of livestock, c) partial direct use value of livestock per capita, and d) partial direct use value of livestock as a percentage of gross provincial domestic product.

Table 5
Partial Direct Use Value of Livestock in Indonesia 2017–2021 (constant 2017 USD billion).

	2017	2018	2019	2020	2021
Beef cattle	17.6	18.9	20.5	21.0	23.8
Layer chicken	7.45	7.83	7.99	8.83	8.84
Broiler chicken	7.93	8.19	8.23	7.40	8.09
Goats	1.99	2.00	2.14	2.25	2.82
Native chickens	1.79	1.72	1.91	2.41	2.53
Sheep	1.72	1.67	1.89	1.91	2.49
Pigs	1.81	1.81	2.06	1.97	2.40
Buffalo	1.39	0.98	1.26	1.21	1.40
Dairy cattle	1.09	1.12	1.13	1.15	1.26
Total	42.7	44.2	47.1	48.2	53.7

The sensitivity of the partial direct use value of livestock to the variation of different input parameters is shown in Fig. 9b. Variations in cattle price have the largest relative impact on livestock value, with a 20% variation in cattle prices leading to a variation of 9.2% in livestock value. Variations of 20% in the chicken price and egg price have an impact on livestock value of 3.7% and 3.5% respectively.

The sensitivity analysis shows that the estimates of biomass and livestock value are relatively robust and can provide a reliable basis for further research activities and development of policy recommendations.

4. Discussion

This paper provides the first published estimates of the biomass and partial direct use value of livestock in Indonesia. The estimated partial direct use value of livestock populations and production in 2021 was USD53.66 billion, around 4.5% of the overall GDP of Indonesia. In comparison, overall value added in agriculture, forestry and fisheries accounted for around 12.4 percent of GDP in 2022 (Statistics Indonesia, 2022b).

Livestock value estimation can be useful for policymakers in terms of lobbying for resources for the sector, and as a basis for determining policies in financing, especially to maintain the existence and growth of livestock through preventing and eradicating livestock diseases, and supplying raw materials for prepared healthy food (Huntington et al., 2021). Having a detailed breakdown of the value of livestock by livestock type and by province can greatly assist in performing cost-benefit analyses of policies related to livestock development and animal health (Nathues et al., 2017).

Overall biomass and partial direct use value of livestock is concentrated on Java island, especially East Java and West Java provinces. Dense populations in small geographic areas combined with high production values imply that disease control measures, including vaccination campaigns and biosecurity measures, could have relatively high benefit-cost ratios in these areas. In comparison, while the absolute values of biomass and partial direct use value of livestock in outlying provinces (including East and West Nusa Tenggara) are low, the per capita values are much higher than in any other part of the country. The biomass of livestock in East Nusa Tenggara is more than double the human biomass in this region, and the partial direct use value of livestock per person is the highest in the country. Significantly, much of this value is in beef cattle, which are used as a store of wealth in rural areas.

Table 6
Descriptive statistics on distribution of biomass and partial direct use value of livestock estimated from stochastic inputs.

	Biomass (kg)	Partial Direct Use Value (USD)
Mean	12,199,422	53,655,542,202
Standard Deviation	621,885	2332,636,246
N	10,000	10,000
Confidence Level (95.0%)	12,190	45,724,365
Lower Bound (95% of sample data)	11,005,622	49,117,318,054
Upper Bound (95% of sample data)	13,416,277	58,157,177,727

Note: livestock value reported here is in 2021 USD.

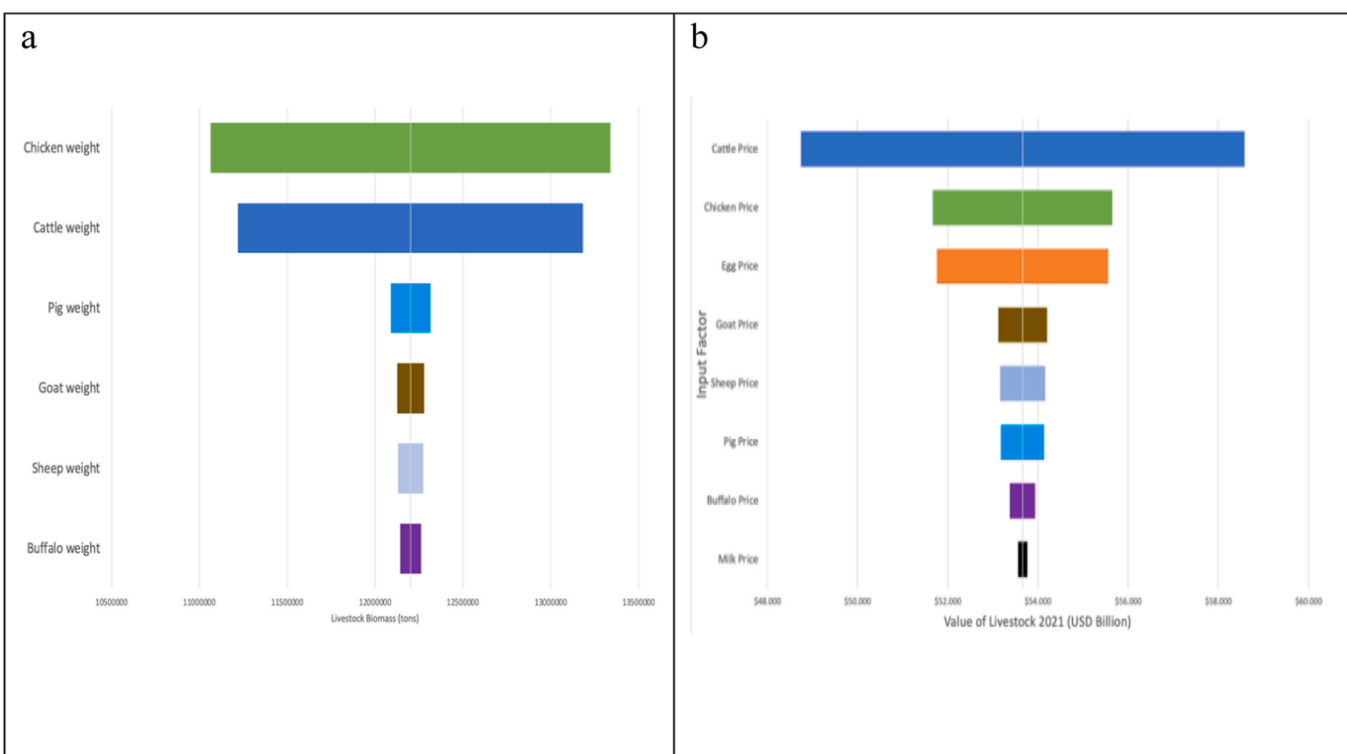

Fig. 9. Tornado plots of sensitivity of a) biomass and b) livestock value to +/- 20% changes in input values.

Any development policies in this region should take into account the potentially devastating livelihood implications of animal disease in these provinces, already the poorest in the country.

A decrease in broiler biomass in 2020 was caused by the COVID-19 pandemic leading to increased unemployment and decreased demand for chicken meat. This led to a short-term decline in broiler production over 2020. By 2021, demand for chicken meat had increased and the population recovered. Decreases in the pig and layer populations were caused by outbreaks of viral diseases; ASF (African swine fever), which was first reported in Indonesia in late 2019 and spread across the country in 2020 and 2021 (Tenaya et al., 2023), and egg drop syndrome in 2017–2018 (Ilham and Saptana, 2019). The decrease in buffalo biomass from 0.33 million tons in 2017–0.22 million tons in 2018 was as least partially due to population decreases associated with inbreeding pressure and scarcity of male buffalo (Praharani and Sianturi, 2018) and a revision of the population calculation based on the SUTAS (inter--census survey) in 2018 (Statistics Indonesia, 2018c).

Overall livestock biomass is 75% of human biomass. Provinces already burdened with high levels of human biomass per km^2 also have increasingly high livestock biomass burdens. Significant biomass loads per km^2, especially in Java and Bali, are leading to pressure on resources (e.g. water and land) and the environment. The co-location of high human and livestock biomass also indicates increased risks for transmission of zoonotic diseases. When designing policies to increase livestock production nationally, the government should therefore take into account existing biomass loads and carrying capacity. This would assist in the development of a comprehensive strategy for expansion of all livestock (including pigs where culturally appropriate) to provinces with sufficient capacity to absorb increased biomass.

4.1. Limitations of study

The value of livestock presented in this paper does not include the significant socio-cultural value of livestock in many parts of Indonesia. Maintaining the existence of livestock means also maintaining the continuity of culture, and conversely, maintaining culture also maintains the existence of livestock which supports the provision of quality food to improve the quality of human resources. The total economic value framework has been used to quantify the cultural and other non-market values of indigenous cattle breeds in other countries (e.g., (Zander et al., 2013; Martin-Collado et al., 2014)), and found this to be over 80% of the total economic value. Thus, our analysis may underestimate the total value of livestock within Indonesia.

There are also data limitations in the calculation of livestock production values. This study concentrates on calculation the value of primary outputs due to the limited availability of data on production and prices of secondary livestock outputs such as manure and hides. While output figures include livestock slaughtered in slaughterhouses and outside slaughterhouses, these figures only represent production that is formally reported. There may be significant amounts of livestock slaughtered in the informal sector for local consumption that are not officially recorded.

Some data series used in calculation of biomass and livestock value have been adjusted during the time period of the analysis in order to align with updated information. A key example is a decrease in the reported numbers of buffalo between 2017 and 2018 resulting from Statistics Indonesia revising figures to follow the results of the BPS SUTAS (Inter-Census Agricultural Survey (Statistics Indonesia, 2018c).

Two-step parameterization and projection validations of population and herd structure was undertaken for beef cattle only. This was undertaken as beef cattle contribute such a large proportion of biomass and value but could also be completed for other species.

4.2. Potential future research

The estimates of biomass and livestock value by species and province presented in this paper could form the basis of further research to generate information to inform policymaking.

First, the livestock value figure presented in this paper can form the base for calculating an animal health loss envelope (AHLE) for Indonesia as a whole or on a province by province or species by species basis. The estimate of livestock value presented in this paper could form the basis of a "current" estimate of value added in livestock, which could be compared with an "ideal" estimate of value added to generate an AHLE for the location/species combination of interest.

Second, based on the provincial estimates of livestock value, a further deep dive into impacts of disease on livestock value at the farmgate level could be taken in particular locations relating to specific species.

Third, future analysis could build on the base provided by this study to expand to cover the value added of livestock at each stage along the value chain (Smith et al., 2020). The calculation of value of livestock presented in this paper is at farmgate level only. The prices used in the calculation are farmgate prices and the form of outputs corresponds to outputs at farm level (for example, slaughter cattle rather than beef). The value chain approach could be expanded to analyse the social, livelihood and economic impact of animal disease on different value chain actors following a similar methodology to that used in Timor-Leste by (Berends et al., 2021) and in Philippines by (Cooper et al., 2022).

CRediT authorship contribution statement

Tarni Louisa Cooper: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Nyak Ilham:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Riyandini Putri:** Writing – review & editing, Investigation, Formal analysis. **Ermin Widjaja:** Writing – review & editing, Investigation, Formal analysis, Data curation. **Widagdo Sri Nugroho:** Writing – review & editing, Formal analysis, Data curation. **Di Mayberry:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Dominic Smith:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Formal analysis, Conceptualization. **Harimurti Nuradji:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Ni Luh Putu Indi Dharmayanti:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by the Australian Centre for International Research (ACIAR) project number LS/2020/156 as an Indonesian Case study under the Global Burden of Animal Diseases (GBADs) Programme.

The authors gratefully acknowledge in-kind institutional support from Griffith University, BRIN and CSIRO.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2024.106164.

References

Adinata, Y., Noor, R.R., Priyanto, R., Cyrilla, L., Sudrajad, P., 2022. Comparison of growth curve models for Ongole Grade cattle. Trop. Anim. Health Prod. *54* (5), 252. https://doi.org/10.1007/s11250-022-03254-z.

Antari, R., Syahniar, T., Mayberry, D., Marsetyo, M., Pamungkas, D., Anderson, S., Poppi, D., 2014. Evaluation of village-based diets for increasing the weight and condition of Ongole (Bos indicus) and Bali (Bos javanicus) cows in Indonesia. Anim. Prod. Sci. *54*, 1368–1373. https://doi.org/10.1071/AN14165.

Baco, S., Malaka, R., Hatta, M., 2019. Pre-weaning performances and mortality rate of calf Bali cattle maintained in the community with smallholder and intensive systems. IOP Conf. Ser. Earth Environ. Sci. *247* https://doi.org/10.1088/1755-1315/247/1/012038.

Bateman, I.J., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Özdemirog¯lu, E., Pearce, D.W., Sugden, R., Swanson, J., 2002. Economic valuation with stated preference techniques: a manual. Edward Elgar Publishing Ltd.

Berends, J., Bendita da Costa Jong, J., Cooper, T.L., Dizyee, K., Morais, O., Pereira, A., Smith, D., Rich, K.M., 2021. Investigating the socio-economic and livelihoods impacts of African Swine fever in timor-leste: an application of spatial group model building [Original Research]. Front. Vet. Sci. *8* https://doi.org/10.3389/fvets.2021.687708.

Budisatria, I.G.S., Udo, H.M.J., Eilers, C.H.A.M., Baliarti, E., van der Zijpp, A.J., 2010. Preferences for sheep or goats in Indonesia. Small Rumin. Res. *88* (1), 16–22. https://doi.org/10.1016/j.smallrumres.2009.11.002.

Budisatria, I.G.S., Guntoro, B., Sulfiar, A., Ibrahim, A., Atmoko, B., 2021. Reproductive management and performances of Bali cow kept by smallholder farmers level with different production systems in South Konawe Regency, Indonesia. IOP Conf. Ser.: Earth Environ. Sci. *782*, 022079 https://doi.org/10.1088/1755-1315/782/2/022079.

Chang, H.-S., Sumantri, I., Panjaitan, T., Hilmiati, N., Prameswari, F., 2020. Beef demand trends in Indonesia and the implications for Australian live cattle and beef exports. Australas. Agribus. Rev. *28* (4).

Cooper, T.L., Smith, D., Gonzales, M.J.C., Maghanay, M.T., Sanderson, S., Cornejo, M.R.J.C., Pineda, L.L., Sagun, R.A.A., Salvacion, O.P., 2022. Beyond numbers: determining the socioeconomic and livelihood impacts of African swine fever and its control in the philippines [Original Research]. Front. Vet. Sci. *8* https://doi.org/10.3389/fvets.2021.734236.

Deze, L.R., Pello, T.O., 2022. Peranan ternak babi pada upacara Adat Bere Tere dalam sudut pandang Adat Budaya Bajawa. J. Pertan. Unggul *1* (1), 38–42.

Doubilet, P., Begg, C.B., Weinstein, M.C., Braun, P., McNeil, B.J., 1985. Probabilistic sensitivity analysis using monte carlo simulation: a practical approach. Med. Decis. Mak. *5* (2), 157–177. https://doi.org/10.1177/0272989×8500500205.

Fairchild, K.W., Misra, L., Shi, Y., 2016. Using triangular distribution for business and finance simulations in excel. J. Financ. Educ. *42* (3-4), 313–336. ⟨http://www.jstor.org/stable/90001156⟩.

Fordyce, G., Anderson, A., McCosker, K., Williams, P., Holroyd, R., Corbet, N., Sullivan, M., 2013. Liveweight prediction from hip height, condition score, fetal age and breed in tropical female cattle. Anim. Prod. Sci. *53*, 275–282. https://doi.org/10.1071/AN12253.

Ilham, N., Saptana, 2019. Fluctuations in the chicken egg price and its determining factors. Anal. Kebijak. Pertan. *17* (1), 27–38.

Statistics Indonesia, 2022b. Statistical Yearbook of Indonesia. Badan Pusat Statistik.

Statistics Indonesia, 2022a. Peternakan Dalam Angka. Badan Pusat Statistik.

Gilbert, W., Marsh, T.L., Chaters, G., Jemberu, W.T., Bruce, M., Steeneveld, W., Sucena Afonso, J., Huntington, B., Rushton, J. (2023). Measuring Disease Cost in Farmed Animals for the Global Burden of Animal Diseases: A Model of the Animal Health-Loss Envelope. [Preprint]..

Haq, M.S., Budisatria, I.G.S., Panjono, P., Maharani, D., 2019. Measuring the sosial economic benefits of Jabres cattle keeping in Bantarkawung Sub-district, Brebes, Central Java, Indonesia. J. Indones. Trop. Anim. Agric. *44* (2), 220–227.

Hidayatuloh, R., Armawan, W., Dwiatmini, S., 2019. Seni laga ketangkasan domba garut dalam perspektif structural fungsional di Desa Cikandang Kecamatan Cikajang Kabupaten Garut. J. Budaya Etn. *3* (2), 115–150.

Huntington, B., Bernardo, T.M., Bondad-Reantaso, M., Bruce, M., Devleesschauwer, B., Gilbert, W., Grace, D., Havelaar, A., Herrero, M., Marsh, T.L., 2021. Global Burden of Animal Diseases: a novel approach to understanding and managing disease in livestock and aquaculture. Rev. Sci. Et. Tech. (Int. Off. Epizoot.) *40* (2), 567–584.

Ilmiah, N., Widodo, S., 2022. Persepsi peternak terhadap pemeliharaan sapi sonokldi Madura. Persepsi peternak terhadap pemeliharaan sapi sonokldi Madura. J. Agribisnis Dan. Ilmu Sos. Ekon. Pertan. (7), 190–197.

Jemberu, W.T., Li, Y., Asfaw, W., Mayberry, D., Schrobback, P., Rushton, J., Knight-Jones, T.J.D., 2022. Population, biomass, and economic value of small ruminants in Ethiopia [Original Research]. Front. Vet. Sci. *9* https://doi.org/10.3389/fvets.2022.972887.

Leslie, E.E.C., Geong, M., Abdurrahman, M., Ward, M.P., Toribio, J.-A.L.M.L., 2015. A description of smallholder pig production systems in eastern Indonesia. Prev. Vet. Med. *118* (4), 319–327. https://doi.org/10.1016/j.prevetmed.2014.12.006.

Statistics Indonesia, 2018b. Peternakan Dalam Angka. Badan Pusat Statistik.

Statistics Indonesia, 2019b. Peternakan Dalam Angka. Badan Pusat Statistik.

Statistics Indonesia, 2018d. Statistical Yearbook of Indonesia. Badan Pusat Statistik.

Statistics Indonesia, 2018a. Agricultural Producer Price Statistics of Animal Husbandry and Fishery Subsector. Badan Pusat Statistik.

Statistics Indonesia, 2011. Pendataan Sapi Potong, Sapi Perah, dan Kerbau. Badan Pusat Statistik, Jakarta, Indonesia.

Statistics Indonesia, 2017a. Agricultural Producer Price Statistics of Animal Husbandry and Fishery Subsector. Badan Pusat Statistik, Jakarta, Indonesia.

Statistics Indonesia, 2019a. Agricultural Producer Price Statistics of Animal Husbandry and Fishery Subsector. Badan Pusat Statistik.

Lesnoff, M. (2013). *DYNMOD: A spreadsheet interface for demographic projections of tropical livestock populations, User's manual version 3*. ⟨http://livtools.cirad.fr⟩.

Li, Y., Mayberry, D., Jemberu, W., Schrobback, P., Acosta, M.H., Jones, T.K., Rushton, J., 2023. Characterising Ethiopian cattle production systems for disease burden analysis. Front Vet. Sci. *10*.

Lutvaniyah, S., Farajallah, D.P., Achmad, Farajallah, A., 2017. Komparasi karakter morfologi sapi madura sonok dan madura pedaging (Morphological characters comparison of sonok and madura cattle). J. Ilmu Pertan. Indones. *22* (1), 67–72. https://doi.org/10.18343/jipi.22.1.67.

Martin-Collado, D., Diaz, C., Drucker, A.G., Carabaño, M.J., Zander, K.K., 2014. Determination of non-market values to inform conservation strategies for the threatened Alistana–Sanabresa cattle breed. Animal *8* (8), 1373–1381. https://doi.org/10.1017/S1751731114000676.

Mayberry, D., Syahniar, T., Antari, R., Ningrum, G., Marsetyo, M., Pamungkas, D., Poppi, D., 2014. Predicting feed intake and liveweight gain of Ongole (Bos indicus) cattle in Indonesia. Anim. Prod. Sci. *54* https://doi.org/10.1071/AN14538.

Microsoft. (2018). *Microsoft Excel*. In ⟨https://office.microsoft.com/excel⟩.

Ministry of Trade. (2021). *Peraturan Menteri Perdagangan Nomor 22, tahun 2021, tentang Tata Cara Pelaporan Distribusi Barang Kebutuhan Pokok dan Barang Penting*. Jakarta.

Mishra, P., Pandey, C., Singh, U., Gupta, A., Sahu, C., Keshri, A., 2019. Descriptive statistics and normality tests for statistical data. Ann. Card. Anaesth. *22*, 67–72. https://doi.org/10.4103/aca.ACA_157_18.

Nathues, H., Alarcon, P., Rushton, J., Jolie, R., Fiebig, K., Jimenez, M., Geurts, V., Nathues, C., 2017. Cost of porcine reproductive and respiratory syndrome virus at individual farm level – an economic disease model. Prev. Vet. Med. *142*, 16–29. https://doi.org/10.1016/j.prevetmed.2017.04.006.

Nugahara, C.D., Maylinda, S., Nasich, M., 2015. Karakteristik sapi sonok dan sapi kerapan pada umur yang berbeda di Kabupaten Pamekasan Pulau Madura. J. Ternak Trop. *16* (1), 55–60.

Praharani, L., Sianturi, R.S.G., 2018. Inbreeding depression and alternative solution in buffaloes. WARTAZOA *28* (1), 1–12.

Sopana, A., Harnovinsah, Sulistyan, R.B., 2023. Madura indigenous communities' local knowledge in the participating planning and budgeting process. J. Ilm. Akunt. Dan. Bisnis *18* (1), 163–178. https://doi.org/10.24843/JIAB.2023.v18.i01.p11.

Statistics Indonesia, 2020d. Statistics of Livestock Slaughtered. Badan Pusat Statistik.

Statistics Indonesia, 2021a. Agricultural Producer Price Statistics of Animal Husbandry and Fishery Subsector. Badan Pusat Statistik, Jakarta, Indonesia.

Statistics Indonesia, 2021d. Statistics of Livestock Slaughtered. Badan Pusat Statistik.

Statistics Indonesia, 2019c. Statistical Yearbook of Indonesia. Badan Pusat Statistik.

Statistics Indonesia, 2019d. Statistics of Livestock Slaughtered. Badan Pusat Statistik.

Statistics Indonesia, 2020b. Peternakan Dalam Angka. Badan Pusat Statistik.

Statistics Indonesia, 2020a. Agricultural Producer Price Statistics of Animal Husbandry and Fishery Subsector. Badan Pusat Statistik, Jakarta, Indonesia.

Statistics Indonesia, 2020c. Statistical Yearbook of Indonesia. Badan Pusat Statistik.

Rafani, I., & Sudaryanto, T. (2020). *Strategic Plan of the Indonesian Ministry of Agriculture 2020-2024*. Retrieved 22-06-2022 from ⟨https://ap.fftc.org.tw/article/1842⟩.

Rushton, J., 2009. The Economics of Animal Health Production. CAB International. https://doi.org/10.1079/9781845931940.0000.

Rushton, J., Huntington, B., Gilbert, W., Herrero, M., Torgerson, P.R., Shaw, A.P.M., Bruce, M., Marsh, T.L., Pendell, D.L., Bernardo, T.M., Stacey, D., Grace, D., Watkins, K., Bondad-Reantaso, M., Devleesschauwer, B., Pigott, D.M., Stone, M., Mesenhowski, S., 2021. Roll-out of the Global Burden of Animal Diseases programme. Lancet *397* (10279), 1045–1046. https://doi.org/10.1016/S0140-6736(21)00189-6.

Sari, R.P., Adi, A.C., 2021. Sistem penentuan kualitas hewan qurban di Indonesia dengan Metode SAW. J. Nas. Teknol. Dan. Sist. Inf. *7* (2), 44–51. https://doi.org/10.25077/TEKNOSI.v7i2.2021.44-51.

Schrobback, P., Dennis, G., Li, Y., Mayberry, D., Shaw, A., Knight-Jones, T., Marsh, T.L., Pendell, D.L., Torgerson, P.R., Gilbert, W., Huntington, B., Raymond, K., Stacey, D. A., Bernardo, T., Bruce, M., McIntyre, K.M., Rushton, J., Herrero, M., 2023. Approximating the global economic (market) value of farmed animals. Glob. Food Secur. *39*, 100722 https://doi.org/10.1016/j.gfs.2023.100722.

Sirajuddin, S.N., Baba, S., Andilolo, D., 2023. Beberapa motivasi masyarakat Totraja memotong ternak kerbau pada adat (Rambu Solo' dan Rambu Tuka). J. Ilmu Dan. Ind. Peternak. *1* (1), 44–55.

Smith, D., Dyer, R., Wandschneider, T., 2020. Making Value Chains Work Better for the Poor: A Toolbook for Value Chain Practitioners, 4th ed. Australian Centre for International Agricultural Research (Eds.).

Statistics Indonesia, 2021b. Peternakan Dalam Angka. Badan Pusat Statistik.

Statistics Indonesia. (2017b). *Statistics of Livestock Slaughtered*.

Statistics Indonesia. (2018c). *The Result of Inter-Census Agricultural Survey 2018*.

Statistics Indonesia. (2018e). *Statistics of Livestock Slaughtered*. Badan Pusat Statistik.

Statistics Indonesia. (2021c). *Statistical Yearbook of Indonesia*. Badan Pusat Statistik.

Suprapto, N., Suliyanah Deta, U.A., Sya'roni, I., Nisa, K., 2022. Glocalization of Bull Racing: A Program for Preservation Kerapan Sapi as Madurese Local Wisdom. Kawalu J. Local Cult. *9* (1), 35–52. https://doi.org/10.32678/kawalu.v9i1.

Tenaya, W.M., Swacita, I.B.N., Wirata, K., Damriyasa, M., Besung, N.K., Suarsana, N., Sari, T.K., Agustina, K.K., 2023. A study of African swine fever virus in Regional VI of the Disease Investigation Center of Denpasar Bali in Indonesia. Vet. World *16* (4), 844–850. https://doi.org/10.14202/vetworld.2023.844-850.

Udo, H.M.J., Budisatria, I.G.S., 2011. Fat-tailed sheep in Indonesia; an essential resource for smallholders. Trop. Anim. Health Prod. *43* (7), 1411–1418. https://doi.org/10.1007/s11250-011-9872-7.

Walpole, S., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G., Roberts, I., 2012. The weight of nations: an estimation of adult human biomass. BMC Public Health *12*, 439. https://doi.org/10.1186/1471-2458-12-439.

Wolf, J., 2020. Quantifying the role of livestock in climate change. In. https://doi.org/10.19103/AS.2020.0064.08.

Wong, J.T., Vance, C., Peters, A., 2021. Refining livestock mortality indicators: a systematic review. Gates Open Res. *5*, 75. https://doi.org/10.12688/gatesopenres.13228.1.

Yitagesu, E., Fentie, T., Kebede, N., Jackson, W., Smith, W., 2022. The magnitude of calf morbidity and mortality and risk factors in smallholder farms across livestock production systems in central Ethiopia. Vet. Med. Sci. *8* (5), 2157–2166. https://doi.org/10.1002/vms3.877.

Zander, K.K., Signorello, G., De Salvo, M., Gandini, G., Drucker, A.G., 2013. Assessing the total economic value of threatened livestock breeds in Italy: implications for conservation policy. Ecol. Econ. *93*, 219–229. https://doi.org/10.1016/j.ecolecon.2013.06.002.