# Applying the California net energy system to growing goats[1]

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**ABSTRACT:** The aim of this review is to describe the main findings of studies carried out during the last decades applying the California net energy system (CNES) in goats. This review also highlights the strengths and pitfalls while using CNES in studies with goats, as well as provides future perspectives on energy requirements of goats. The nonlinear relationship between heat production and metabolizable energy intake was used to estimate net energy requirements for maintenance ($NE_m$). Our studies showed that $NE_m$ of intact and castrated male Saanen goats were approximately 15% greater than female Saanen goats. Similarly, $NE_m$ of meat goats (i.e., >50% Boer) was 8.5% greater than $NE_m$ of dairy and indigenous goats. The first partial derivative of allometric equations using empty body weight (EBW) as independent variable and body energy as dependent variable was used to estimate net energy requirements for gain ($NE_g$). In this matter, female Saanen goats had greater $NE_g$ than males; also, castrated males had greater $NE_g$ than intact males. This means that females have more body fat than males when evaluated at a given EBW or that degree of maturity affects $NE_g$. Our preliminary results showed that indigenous goats had $NE_g$ 14% and 27.5% greater than meat and dairy goats, respectively. Sex and genotype also affect the efficiency of energy use for growth. The present study suggests that losses in urine and methane in goats are lower than previously reported for bovine and sheep, resulting in greater metabolizable energy:digestible energy ratio (i.e., 0.87 to 0.90). It was demonstrated that the CNES successfully works for goats and that the use of comparative slaughter technique enhances the understanding of energy partition in this species, allowing the development of models applied specifically to goat. However, these models require their evaluation in real-world conditions, permitting continuous adjustments.

**Key words:** comparative slaughter, degree of maturity, efficiency of utilization, metabolizable energy, requirements for growth, requirements for maintenance

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## INTRODUCTION

In late 1950s, the California net energy system (CNES) was developed to attend an increasing demand for revisiting the evaluation of the energy content of feedstuffs used in the beef cattle industry. It was based on data using the comparative slaughter technique to measure energy recovered in the body of beef cattle, and one

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of the main contributions of this system was the proposition of adopting different net energy (NE) values according to the proportion of NE used for maintenance and weight gain. Thus, CNES adopted one value of NE for maintenance ($NE_m$) and other value for weight gain ($NE_g$; Lofgreen and Garrett, 1968).

It is important to highlight that the CNES was successful accepted by the beef industry, and it became the precursor of many feeding systems for dairy cattle and sheep (Ferrel and Oltjen, 2008). The application of the CNES in goats has been used most exclusively by Brazilian researchers.

In Brazil, CNES started being used as the basis for expressing energy requirements for maintenance and production of bovine and goats in a series of experiments conducted in 1980s. In 1989, Dr. Resende and Dr. Silva Sobrinho defended the first dissertations at the Universidade Federal de Viçosa aiming to determine nutritional requirements of growing (Resende, 1989) and lactating goats (Silva Sobrinho, 1989), respectively. Both researchers were hired at the recently created Universidade Estadual Paulista (UNESP), and they started their research program working with different small ruminant species; Dr. Resende continued working with goats, and Dr. Garcia Sobrinho has dedicated his career to work with sheep. Under the supervision of Dr. Resende, several thesis and dissertations were defended aiming to estimate energy requirements of goats, especially growing goats (Figure 1). Later, Dr. Resende's former students initiated their research programs still working with goats; in the Southeast states of Brazil, the studies focused on dairy and meat goat by research teams led by Dr. Teixeira and Dr. Fernandes, and in the Northeast states of Brazil, Dr. Medeiros and Dr. Carvalho have focused on indigenous goats (Figure 1). Initially, the majority of the studies were carried out with male goats, varying the goat breeds used in the studies. More recently, there have been an effort to investigate the effect of sex and genotype on the energy requirements of goats, especially at UNESP (Figure 1).

The Brazilian studies applying the CNES to goats have generated considerable amount of data that has contributed to improve our understanding of energy requirements of goats and have also been used in the feeding systems developed in other countries, such as INRA (2018).

Our objective in this review is to describe the main findings from the studies applying the CNES in growing goats. This review also highlights the strengths and pitfalls while using CNES in studies with goats, as well as provides future perspectives on energy requirements of goats.

## GENERAL METHODOLOGICAL ASPECTS WHEN APPLYING CNES TO GOATS

The comparative slaughter technique that is the basis of the CNES consists in estimating the

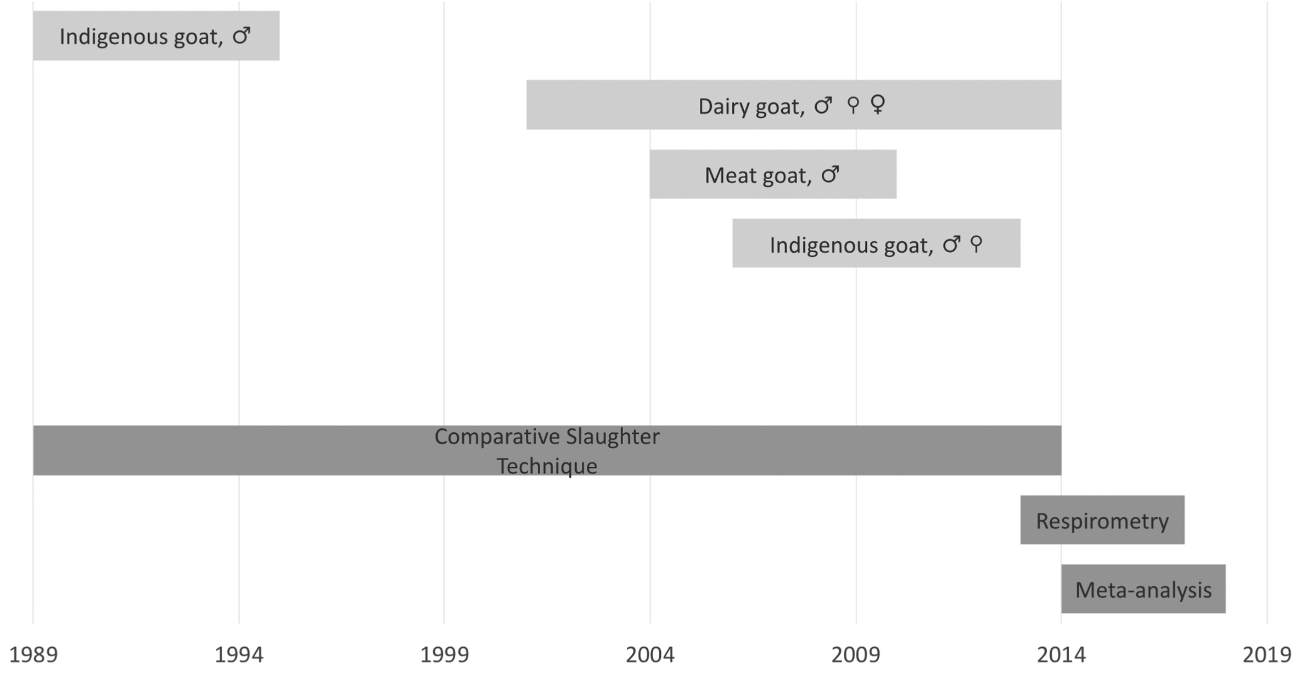

**Figure 1.** Timeline showing studies applying the California net energy system to goats in Brazil (♂ represents intact male goats, ⚲ represents castrated male goats, and ♀ represents female goats).

recovered energy (RE), that is the change in body energy content of animals during a given period of time. It assumes that the body composition of the experimental group of animals at the beginning of the study can be accurately estimated from the body composition of similar animals from the studied population that were slaughtered at the beginning of the experimental period (also called baseline animals).

The selection of baseline animals is crucial for the success of the technique. Our studies have used from five to eight goats to represent baseline animals, reporting a coefficient of variation between 2.5% and 10% for body protein, between 8% and 30% for body fat, and between 5% and 15% for body energy (average of baseline goats of studies showed in Table 1).

The comparative slaughter studies used by Lofgreen and Garrett (1968) estimated body composition using specific gravity measurements of carcasses of beef cattle. Otherwise, the body composition of goats has been accurately estimated using the direct method (i.e., consists in the chemical composition of all tissues of the whole empty body of a slaughtered animal). When using the direct method, caution in slaughtering and sample processing is essential. Usually, prior to slaughter, animals are solid fasted for 12 to 16 h to facilitate handling during slaughter. Slaughter procedures should be carried in accordance with regulatory standards established by the animal care and use committee. Slaughter proceedings in studies with goats were performed by stunning the goat kids with an electric shock and killed by exsanguination using conventional humane procedures (Fernandes et al., 2007; Bompadre et al., 2014; Medeiros et al., 2014; Ferreira et al., 2015) or with a captive bolt pistol followed by severing the jugular vein and carotid artery (Almeida et al., 2015a,b; Figueiredo et al., 2017). All procedures used across studies were reviewed and approved by the University's Animal Care and Use Committee. Blood was weighed and sampled to be later mixed and chemically analyzed with other body parts. The body was then separated into internal organs (liver, heart, lungs and trachea, tongue, kidneys, and spleen) and emptied and cleaned digestive tract (rumen, reticulum, omasum, abomasum, and small and large intestines), hide, head, feet, and carcass. All body parts were weighed separately, frozen, ground, and mixed to be later chemically analyzed, except the hide that was analyzed separately.

The empty body weight (EBW) was calculated as the difference between body weight at slaughter and the contents of the gastrointestinal tract and bladder. Considering that a robust estimative of EBW is critical in the comparative slaughter studies with goats, Campos et al. (2017) gathered individual records of 311 growing goats to develop empirical models to predict EBW from BW. They found that there is no need to use different models for goats of different sex; however, different models are required to predict EBW from BW for suckling and post-weaning Saanen goats. In general, suckling goats show a decreasing relationship between EBW and BW, oppositely it remained relatively constant in post-weaning goats (Campos et al., 2017). Moreover, goats of different genotypes have different gastrointestinal relative capacity, which implied in the need of using different empirical

**Table 1.** Summary of the studies using the California net energy system with growing goats in Brazil

| Study | Reference | *n*[1] | Genotype | Sex[2] | BW[3] range, kg |
|---|---|---|---|---|---|
| 1 | Fernandes et al. (2007) | 33 | ¾ Boer ¼ Saanen | M | 20.3 to 36.6 |
| 2 | Alves et al. (2008) | 26 | Indigenous | M | 15.6 to 26.7 |
| 3 | Nóbrega et al. (2009) | 24 | ½ Boer ½ Indigenous | M | 24.5 to 35.0 |
| 4 | Busato (2010) | 60 | ½ Boer ½ Indigenous and Indigenous | M | 7.25 to 39.5 |
| 5 | Gomes (2011) | 18 | Saanen | M | 30.0 to 51.0 |
| 6 | Bompadre et al. (2014) | 19 | Saanen | M/F/C | 4.70 to 16.5 |
| 7 | Medeiros et al. (2014) | 23 | Saanen | M | 5.10 to 21.6 |
| 8 | Almeida et al. (2015a,b) | 14 | Saanen | M/F/C | 27.6 to 46.6 |
| 9 | Ferreira et al. (2015) | 45 | Saanen | C | 20.6 to 35.5 |
| 10 | Figueiredo et al. (2016) | 30 | Saanen | F | 29.5 to 46.0 |
| 11 | Figueiredo et al. (2017) | 20 | Saanen | M/F/C | 14.7 to 34.0 |
| 12 | Teixeira et al. (2017) | 39 | ½ Boer ½ Saanen | M/F/C | 4.30 to 26.3 |
| 13 | Resende et al. (2018) | 38 | Indigenous | M | 4.90 to 27.8 |

[1] Total number of goat records by study.

[2] M = intact male, F = female, C = castrated male.

[3] BW = body weight.

model according to the goat genotype (Campos et al., 2017).

Other crucial aspect of applying CNES to goats is to accurately estimate metabolizable energy (ME) intake (MEI), which is dependent on the accurate measurement of daily dry matter (DM) and nutrient intake and an accurate estimate of ME of diet. The findings showed in this review are from studies using feedlot goats; thus, the daily measurement of intake was obtained without major complications. In this matter, to avoid high selectivity by goats it is recommended the use of pelleted or finely grinded diet (the later has been the option used in the Brazilian studies). The ME is determined by deducting from the gross energy (GE) the energy of feces, urine, and methane. Thus, the accurate measurement of feces and urine excretion is crucial. During measurements, the goats were individually housed in digestibility cages, which allowed total collection of feces and urine. The collection period adopted in the studies varied from 5 to 7 d. During digestibility trials, the methane emission is generally estimated using equations from the literature (i.e., Blaxter and Clapperton, 1965); however, more recently different approaches have been applied. The approaches used for estimating methane emission will be addressed later in this review. As the studies were based on long-term comparative slaughter trial, there were a concern related to changes in the quality of the diet. To address this concern, the studies conducted at UNESP used a standard diet, based mainly on ground corn, soybean meal, and a roughage that consisted of whole corn plants (60% to 70% moisture) chopped when the kernel milk line reaches approximately two-thirds of the distance down the kernel, air dried until it reaches approximately 10% moisture, and then the dried chopped material was ground to pass a 4-mm screen (Fernandes et al., 2007). The use of standard diet across studies allows to focus on the animal factors affecting the requirements (i.e., sex, genotype, and physiological stage).

## ESTIMATION OF ENERGY REQUIREMENTS FOR MAINTENANCE IN GOATS

Conceptually, the $NE_m$ is the energy lost as heat during basal metabolism of a fasted animal, also known as fasting heat production ($H_eE$; NRC, 1981). When using comparative slaughter technique, heat production (HP) is determined indirectly by subtracting RE from MEI (i.e., HP = MEI − RE). The RE is measured as the change in body energy content of animals fed at various levels of MEI, which can be achieved by quantitative feed restriction (i.e., different amounts of the same diet; Tedeschi et al., 2002; Almeida et al., 2015a; Figueiredo et al., 2017; Pereira et al., 2017) or by qualitative feed restriction (i.e., varying proportion of ingredients of the diet, such as the roughage; Chizzotti et al., 2007; Pereira et al., 2014). Although qualitative restriction will promote different MEI, allowing the determination of $NE_m$ of the diet, different diets yield different efficiencies of ME use, which could bias the real efficiencies of ME use by the animal. Irrespective of the approach adopted, the different levels of MEI allows to compute a relationship between HP and MEI that is described by a nonlinear equation: $HP = \beta_0 \times \exp^{(\beta 1 \times MEI)}$. The $NE_m$ is the $\beta_0$, which is the HP at zero MEI. Originally, Lofgreen and Garrett (1968) fitted the linearized relationship between HP and MEI, by using a semi logarithmic equation: $\text{Log } HP = \beta_0 + \beta_1 \times MEI$. The linearized approach had been widely used; however, advances in statistical software have facilitated the application of nonlinear models. In our laboratory, the nonlinear regression of HP on MEI has been fitted using the SAS macro %NLINMIX, and the proceedings NLIN or NLMIXED (SAS Inst. Inc.; version 9.4). The application of these two approaches (linear and nonlinear models) has indicated that the nonlinear approach shows lower residual variance and better fit (Almeida et al., 2015a).

Overall, the CNES has been successfully used to estimate energy requirements for maintenance in growing goats, as demonstrated by a total of 13 comparative slaughter studies, in which the BW of the goats varied from 5 to 45 kg BW (Table 1). The ME of diets from these studies varied from 2.4 to 2.9 Mcal/kg of DM and goats were fed different levels of intake (i.e., from two to four levels, from ad libitum to approximately maintenance level). These individual studies were aggregated in a meta-analysis (Souza, 2017) that showed that the $\beta_0$ and $\beta_1$ parameters differed between sex, indicating that $NE_m$ of intact and castrated male Saanen goats were approximately 15% greater than female Saanen goats (75.0 vs. 63.6 kcal/kg$^{0.75}$ EBW, respectively). Even though the studies used in the meta-analysis covered goats from approximately birth to 18 mo old (Figure 2), an effect of age in the $NE_m$ was not observed. On the other hand, Harter et al. (2017), in a comparative slaughter study with adult female goats (i.e., approximately 4 yr old), estimated $NE_m$ as 47.1 kcal/kg$^{0.75}$ EBW, which was 26% lower than $NE_m$ reported for growing female goats (Souza, 2017), suggesting a decrease in $NE_m$ when goats are older than 18 mo old.

The effect of genotype (dairy, meat, and indigenous) in the $NE_m$ of male goats has also been investigated in studies using CNES (Fernandes et al., 2007; Busato, 2010; Bompadre et al., 2014; Medeiros et al., 2014; Almeida et al., 2015a; Figueiredo et al., 2017; Teixeira et al., 2017; Resende et al., 2018). Our findings showed that $NE_m$ of meat goats (i.e., >50% Boer) was 8.5% greater (80.3 kcal/kg$^{0.75}$ EBW) than other genotypes (i.e., dairy and indigenous). The parameters of the equation did not differ between dairy and indigenous goat genotypes, resulting in $NE_m$ of 74.0 kcal/kg$^{0.75}$ EBW (Table 2). Originally, Lofgreen and Garrett (1968) reported 77 kcal/kg$^{0.75}$ EBW, with no distinction among genotypes. Later, differences in beef cattle breeds was accounted (NASEM, 2016) that suggested that *Bos indicus*, except Nellore, requires up to 10% less energy for maintenance than *Bos taurus*, with crossbreds showing an intermediate $NE_m$ value. However, NASEM (2016) pointed out that under some circumstances, such as genetic improvement or high growth rates, this 10% adjustment might not be necessary. Moreover, genotype–environment interactions may result in a population of animals

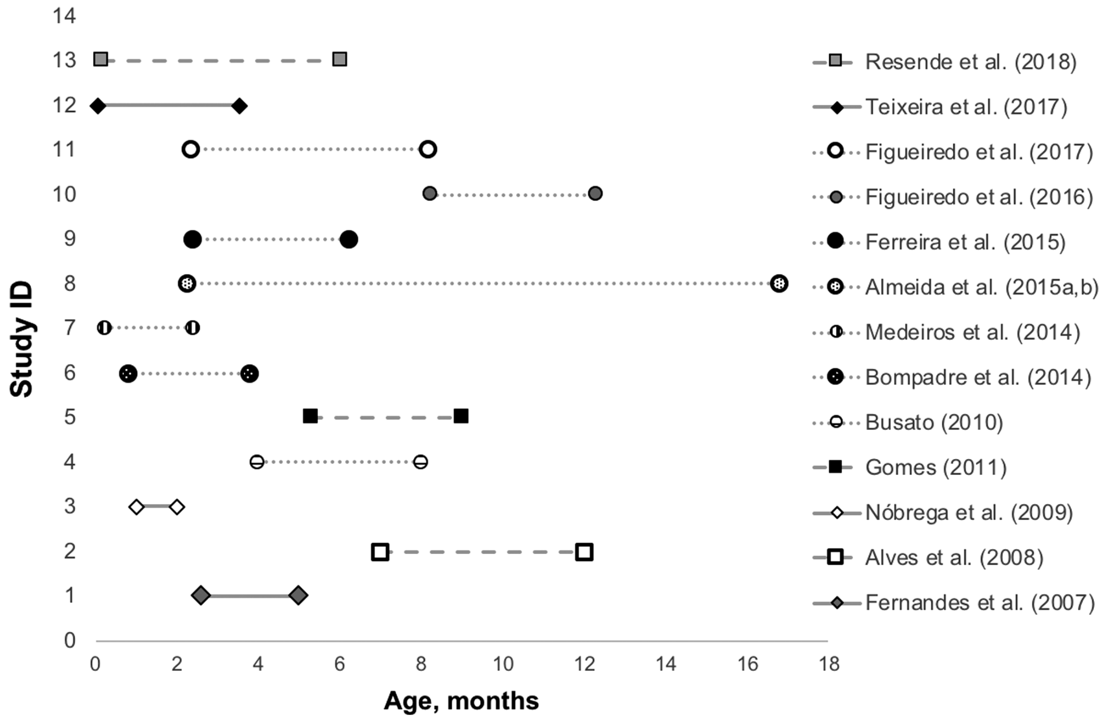

**Figure 2.** Age range throughout studies: squares represent studies with Indigenous goats, diamonds represent studies with Boer crossbreds, and circles represent studies with Saanen goats.

**Table 2.** Summary of energy requirements for maintenance (kcal/kg$^{0.75}$ EBW) of goats applying CNES

| Genotype/breed | Sex | $n$[1] | $NE_m$[2] | $ME_m$[3] | $k_m$[4] |
|---|---|---|---|---|---|
| Effect of sex on maintenance requirements[5] | | | | | |
| Saanen | Female | 60 | 63.6 | 101.2 | 0.63 |
| Saanen | Castrated males | 80 | 75.0 | 120.9 | 0.62 |
| Saanen | Males | 97 | 75.0 | 120.9 | 0.62 |
| Effect of genotype on maintenance requirements[6] | | | | | |
| Dairy[7] | Males | 97 | 74.0 | 118.7 | 0.62 |
| Indigenous | Males | 55 | 74.0 | 118.7 | 0.62 |
| Meat | Males | 87 | 80.3 | 125.3 | 0.64 |

[1] Total number of goat records used for the estimative.

[2] Net energy requirements for maintenance, in kcal/kg$^{0.75}$ EBW.

[3] Metabolizable energy requirements for maintenance, in kcal/kg$^{0.75}$ EBW.

[4] Efficiency of use of metabolizable energy for maintenance.

[5] Results adapted from Souza (2017).

[6] Data not shown.

[7] Saanen goats were considered dairy type, goats were considered meat type when they were ≥50% Boer, undefined breed + local breeds were pooled in indigenous goats.

highly adapted to a given environment (NASEM, 2016), affecting the expected $NE_m$. This concept can be particularly relevant for goats because they are reared in a wide range of systems widespread worldwide (Cannas et al., 2008), reinforcing the need of studies comparing $NE_m$ between different goat breeds or genotypes.

The majority of feeding systems for goats (CSIRO, 2007; INRA, 2007; NRC, 2007; Tedeschi et al., 2010a) are based on ME concepts, which are estimated either from the conversion of NE to ME using efficiency of utilization ($k$) or from the direct estimation of ME requirements obtained by regressing RE on MEI (i.e., based on comparative slaughter studies). This approach allows to compute the ME requirement for maintenance ($ME_m$) by iteratively solving the equation ($HP = \beta_0 \times \exp^{(\beta 1 \times MEI)}$) assuming that the $ME_m$ equals the value at which HP is equal to MEI, then the efficiency of use of ME for maintenance ($k_m$) is computed as $NE_m/ME_m$. Using this approach, $ME_m$ differences between sex and genotypes followed same pattern of $NE_m$ differences. In summary, $ME_m$ of male and of castrated males are similar and approximately 20% greater than females (Souza, 2017; Table 2). Regarding genotypes differences, $ME_m$ of Saanen and Indigenous male goats are similar and approximately 5% lower than meat male goats (Table 2). Sources of variation in $ME_m$ are directly related to $NE_m$ and $k_m$ estimates (Resende et al., 2018). Feeding systems has shown that $k_m$ may vary from 0.56 to 0.75 for goats (Cannas et al., 2008). However, the estimated values of $k_m$ in our studies showed a narrower range (from 0.62 to 0.64, Table 2), which might be a consequence of adopting similar diets in our comparative slaughter studies with goats.

## ESTIMATION OF ENERGY REQUIREMENTS FOR GAIN IN GOATS

The $NE_g$ estimates described by Lofgreen and Garrett (1968), involves the examination of body energy content at different EBW. Then, allometric equations are fitted using EBW as independent variable and body energy as dependent variable: Body energy = $\beta_0 \times EBW^{\beta 1}$. In this regard, the allometric equation may be fitted in its native form (i.e., nonlinear) or linearized (i.e., using log-transformation). The linearized allometric equation (log-log transformation) is easier to converge, but the linearization process also has its own issues (McCuen et al., 1990; Packard, 2009). Procedures such as the NLMIXED, NLIN, and the macro %NLINMIX (SAS Inst. Inc.; version 9.4) may be applied when convergence criteria are met and parameter estimates are reliable; however, it may not happen in several cases. In our research group, the use of one or another has been dictated by the pattern of the standardized conditional residuals inherent to the database. In this sense, the nonlinear allometric equation undertakes that the errors are additive in the native scale (i.e., homogeneous variance with respect to EBW). While, the linearization is suitable in case of multiplicative errors in the native scale (i.e., variance proportional to EBW. See Souza et al., 2017 for further details). The $NE_g$ (kcal/kg of EBW gain) is the solution of the first partial derivative of the allometric equations with respect to EBW for a given EBW.

Because $NE_g$ relies on body composition, any factor that alter protein and fat deposition (i.e., growth pattern) would affect $NE_g$. For instance, Souza et al. (2017) published a meta-analysis, in which they reported greater $NE_g$ for female Saanen goats than males, likewise they found greater $NE_g$ for castrated males than intact males. Souza et al. (2017) explained such pattern by body fat that was greater in females (95.1 g/kg EBW) than castrated males (69.8 g/kg EBW) and intact males (51.3 g/kg EBW). This means that females have more body fat than males when evaluated at a given EBW. In this sense, the observed effect of sex on $NE_g$ might be canceled out if goats are evaluated at similar degree of maturity. During growth, protein and ash content increase at similar rates of EBW reaching a plateau after maturity (Moulton, 1923; NRC, 2000). Fat depots also increase as the animal grows; however, after maturity, the fat deposition is exponential (Geay, 1984; Lawrence et al., 2012; Almeida et al., 2016). Considering the aforementioned growth pattern, Almeida et al. (2016) using body composition data investigated the mature weight of Saanen goats of different sexes. When accounting for degree of maturity (i.e., current EBW/mature EBW) in $NE_g$ estimate differences across sexes disappear as reported by Souza et al. (2017; i.e., applying to mature weights estimated by Almeida et al., 2016). This indicate that maturity degree should be accounted in $NE_g$ estimates.

Other factor that may affect growth pattern, thus maturity degree, of a given goat is genotype. In this matter, our research group have been working with a database to depict genotype effect on $NE_g$. This database has only records of intact males because the body composition of females and castrate males within tested genotypes (i.e., meat and indigenous) were missing. Our preliminary results showed that indigenous goats had $NE_g$ 14% and

27.5% greater than meat and dairy goats, respectively (Teixeira et al., 2018). In this sense, one may question whether comparing the $NE_g$ of an indigenous goat at a given BW is compatible to the $NE_g$ of a meat goat at the same given BW. Male Saanen goats reach maturity near 50 kg BW (Almeida et al., 2016), which is an unrealistic BW for indigenous goats, which have smaller body frame (i.e., adult BW up to 40 kg BW according to Lôbo et al., 2010). In this regard, more information on body composition is needed to depict the mature weight of goats from different genotypes, as Almeida et al. (2016) did for Saanen goats.

The shift of priority of tissue accretion during growth affects the efficiency for gain of the animal (Tedeschi et al., 2010b). In this regard, the simplest approach to estimating the net availability of MEI for growth has been assessed by a regression of RE on MEI: $RE = ME_m + k_{m+g} \times MEI$ (Tedeschi et al., 2010b), whose slope represents the partial efficiency of ME utilization for maintenance and growth ($k_{m+g}$) instead the partial efficiency of ME utilization for growth ($k_g$). Contrariwise, the value of $k_g$ can be conceptually estimated as the slope of the regression equation of MEI above the maintenance level on RE, assuming that RE is null when MEI above maintenance = 0 (model intercept equal to 0): $RE = k_g \times (MEI - ME_m)$. Hence, it is expected that values of $k_{m+g}$ might be slightly greater than $k_g$ because partial efficiency of the use of the ME for maintenance purposes are greater than for growth. For instance, Fernandes et al. (2007) and Bompadre et al. (2014) reported $k_{m+g}$ of 0.42 and 0.47, respectively, whereas other studies reported a $k_g$ for male goats varying from 0.31 to 0.32 (Almeida et al., 2015a; Figueiredo et al., 2017; Teixeira et al., 2017; Resende et al., 2018). These similar values of $k_g$ may be attributed to similarities in the diet because the dietary energy concentration and body composition of the gained mass are the main factors affecting $k_g$ (Tedeschi et al., 2010b).

To understand how composition of the gained mass affects $k_g$, the efficiencies related to energy retention as lipid ($k_f$) and protein ($k_p$) have been modeled by using a multiple linear regression: $MEI = ME_m + (1/k_p) \times REp + (1/k_f) \times REf$, where MEI is metabolizable energy intake, $ME_m$ is metabolizable energy for maintenance, $k_p$ and $k_f$ are the efficiencies related to protein and fat deposition, and REp and REf are the retained energy as protein and fat, respectively (Birkett and de Lange, 2001). In general, reported values of $k_p$ and $k_f$ have indicated that storing energy as protein in growing animals is energetically less efficient than storing energy as fat (Tedeschi et al., 2010b) because the higher cost of protein turnover will increase the HP and decrease the ME efficiency (Owens et al., 1995; Chizzotti et al., 2008). For instance, protein and fat accretion efficiencies for cattle were reported as 0.20 and 0.75, respectively (Geay, 1984). Other previous paper reported a protein accretion efficiency of 0.34 and a fat accretion efficiency of 0.79, without differences between breed and sex (heifers, steers, and bulls; Chizzotti et al., 2007). Results from Saanen goats also revealed that the $k_p$ (0.21) was lower than $k_f$ (0.81), and both efficiencies did not differ between sexes (Souza, 2017). Likewise, it has been reported that the uncertainty in the estimates for $k_f$ is greater than in the values for $k_p$ (Souza, 2017). As illustrated, variations in $k_p$ and $k_f$ may be a result from the collinearity between fat, protein, and RE inherent to multiple regression methods, which hinders the partition of energy intake between fat and protein gain.

## ME:DE RATIO

The CNES proposed by Lofgreen and Garrett (1968)relies on the ME information to estimate MEI, and fit the association between HP and MEI aiming to estimate NE requirements for maintenance. For practical purposes, the estimation of ME in feeds is essential in matching the requirements with proper energy input. However, for accounting ME, the inefficiencies of energy use must be considered in the sense of energy losses. In this regard, digestible energy (DE) is obtained by subtracting the energy losses in feces from GE, and ME is calculated by subtracting the energy losses in urine and gases from DE.

The scope of this section is to focus on the DE conversion to ME, evaluating the ME:DE ratio, that has been historically used in the CNES methodology. Revisiting DE is essential while handling ME:DE ratio, which by definition has a numerator (i.e., ME) and a denominator (i.e., DE); thus, both may influence the ME:DE as a whole. For instance, the NASEM (2016) stated that energy digestibility may vary from 30 up to 90%, depending on diet quality. Studies conducted at UNESP resulted in an average fecal energy loss in growing Saanen goats of 29.6 ± 2.38% GE (Figure 3).

The ME itself may also vary due to diet (e.g., roughage:concentrate ratio, fat supplementation, nitrogen level), animal (e.g., species, category, physiological state), among others. In this regard, any nutritional manipulation that modify ruminal fermentation (i.e., gas production) and urinary

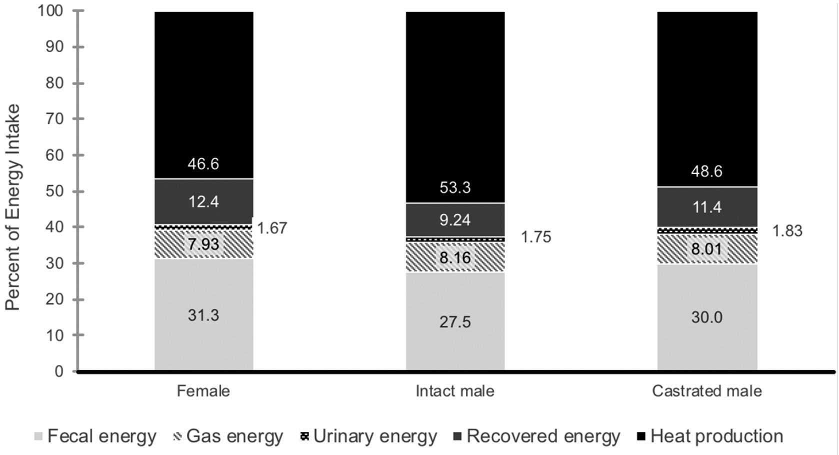

**Figure 3.** Energy partition across sexes in studies with growing goats. No difference between sexes was observed in energy losses in feces, urine, or gasses ($P \geq 0.35$), using MIXED procedure of SAS (SAS Inst. Inc.; version 9.4). Energy losses from gaseous products of digestion were predicted according to Blaxter and Clapperton (1965) as: Gas energy, kcal/d = GEI, kcal/d × (4.28 + 0.059 × DGE,%); GEI = gross energy intake; DGE = digestible gross energy.

energy losses might alter ME, which in turn may affect the ME:DE ratio. For instance, urinary energy losses reported by literature ranges from 3.27% to 5.57% GE in cattle (Reynolds et al., 1991; Hales et al., 2013; Jennings et al., 2018), which is greater than what we have been finding in goat studies (1.87 ± 0.601% GE; Figure 3). Energy losses in urine is mainly due to urea, that is subjected to complex processes of N metabolism in ruminants, linked to dietary nitrogen input and efficiency of N use (e.g., N recycling). Aforementioned difference is consistent with the greater N recycling reported in goats compared with other ruminants (Harmeyer and Martens, 1980).

According to Blaxter and Clapperton (1965), the heat of fermentation within the gut (gaseous losses) can account for 6.2% to 10.8% of GE in ruminants. Studies conducted in our research group traditionally use estimates of gaseous energy loss as suggested by Blaxter and Clapperton (1965), resulting in mean value of 8.14 ± 0.433% GE (Figure 3). In this matter, variation in losses due to methane are not well understood because it relies on ruminal microbiota complex interactions, which may vary accordingly feed additives, feed regimen, roughage:concentrate ratio, and measurement methodologies (Beauchemin et al., 2008; Hales et al., 2014; Knapp et al., 2014; Hill et al., 2016; Lima et al., 2016; Tapio et al., 2017; Hristov et al., 2018). Considering that the energy losses in gases comprise mainly methane produced by ruminants, recent studies at UNESP (Figure 1) focused on measuring methane production in goats. Our first attempt was applying the sulfur hexafluoride tracer technique reported, the results showed lower gaseous energy losses than that estimated using the equation by Blaxter and Clapperton (1965; gaseous energy losses of 5.80 ± 0.60% GE, according to Lima et al., 2016). The second approach we used was applying respirometry, in which Fernandes et al. (2017) also reported lower methane production by Saanen and Alpine goats (5.1% and 6.5% GE, respectively) when compared with that estimated using the equation by Blaxter and Clapperton (1965).

Aware that energy losses in urine and gases are prone to such variation, one may think that ME:DE ratio would also vary. In this regard, the use of the constant value of 0.82 (i.e., the basis for calculating ME; Garrett, 1980) has been amended (Galyean et al., 2016; Valadares-Filho et al., 2016). We also evaluated the suitability of applying the constant value of 0.82 to convert the DE to ME. In this sense, the measured ME in our metabolism trial was considered observed values, and ME obtained using the constant 0.82 of DE was taken as a predicted value (Figure 4). In this sense, we have found that the use of the constant (i.e., 0.82) to calculate ME, underestimated ME in 132.3 ± 7.24 kcal/kg DM, on average ($P < 0.01$). As we detected slope bias ($P < 0.01$), bias increases with predicted ME, showing bias of 66.6 kcal/kg at lower predicted ME and 177 kcal/kg at higher predicted ME.

As an alternative, Galyean et al., (2016) suggested the use of a linear regression equation with dietary ME concentration as the dependent variable and dietary DE concentration as the independent variable. Using this approach, we found intercept and slope (−0.0862 and 0.888, respectively; Figure 5) outside the 95% confidence intervals of both intercept (−0.503 to −0.0968) and slope (0.902 to 1.02) estimated by Galyean et al., (2016), what suggests different ME:DE relationship in goats

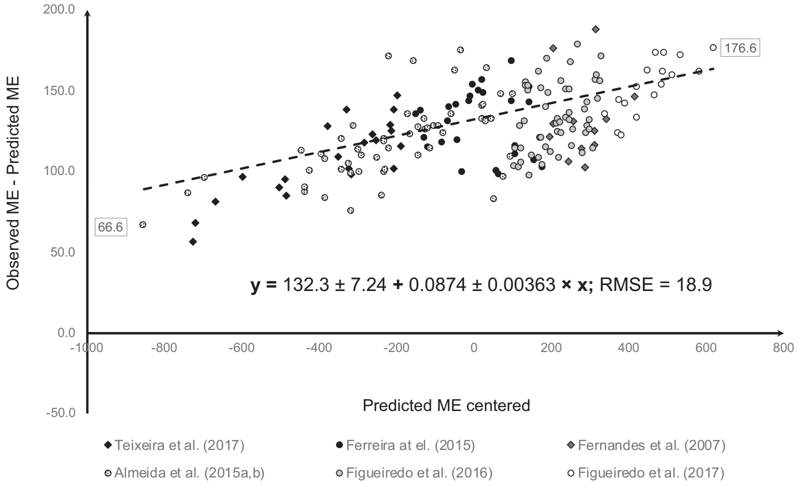

**Figure 4.** Linear regression of residual (observed ME minus predicted ME = 0.82 × DE) on the predicted values centered on their mean (ME = metabolizable energy; DE = digestible energy). The intercept of the linear regression equation was used to estimate mean biases, whereas linear bias (i.e., systematic bias) was assessed using the slope of the regression equations (St-Pierre, 2003), using MIXED procedure of SAS (SAS Inst. Inc.; version 9.4). Diamonds represent studies with Boer crossbreds, and circles represent studies with Saanen goats.

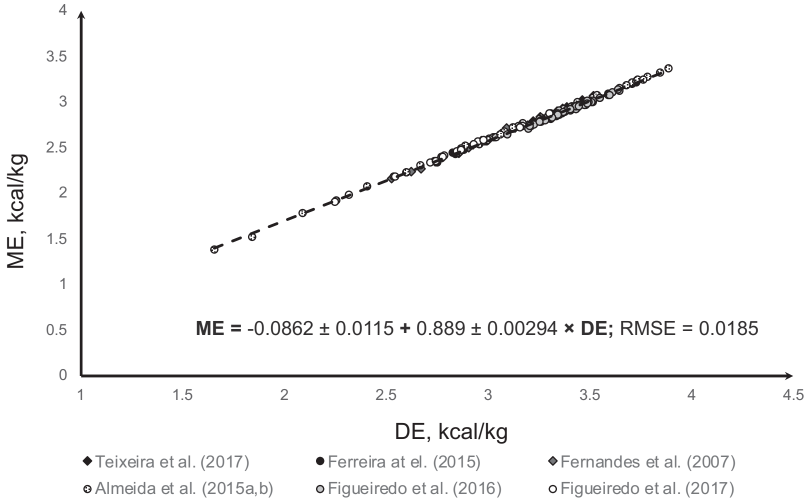

**Figure 5.** Linear regression equation of dietary ME concentration on dietary DE concentration (ME = metabolizable energy; DE = digestible energy). Fitted using MIXED procedure of SAS (SAS Inst. Inc.; version 9.4). Diamonds represent studies with Boer crossbreds, and circles represent studies with Saanen goats.

(Figure 5). A Monte Carlo simulation using parameter estimates in Figure 5 showed that ME:DE may vary from 0.87 to 0.90 (i.e., 95% confidence interval). The presented ME:DE relationship suggests that losses in urine and methane in goats are lower than previously reported for bovine and sheep, resulting in greater ME:DE ratio.

## CONCLUSIONS

The development of CNES boosted the application of net systems to beef cattle and was clearly demonstrated to work for goats. The use of comparative slaughter greatly improved the understanding of energy partition in goats regarding differences due to sex and genotype, as well as the knowledge of their efficiencies of ME use, contributing to efforts toward the development of net system for goats.

Due to the variety of environment goats can be raised, it is crucial to estimate the energy partitioning of grazing goats, not only under the perspective of the diversity of diets, but also due to the level of activity grazing goats perform and the energy costs related to it. Therefore, considering the database we have developed with goats, one of the main aspects to focus on the future is to increase the diversity of diets, as it will allow more robust estimation of efficiency of use of energy. In addition, the simple approach applied for estimating efficiencies fails in incorporating body composition information, for instance, $k_g$ can be significantly improved if incorporated the ratio of protein and fat deposition in its estimative.

The robustness of this database is greatly due to the accuracy of the body composition data, which was entirely obtained using the direct method. The future challenge is to deliver alternative methods that allow other deployment of carcass or empty body or that allow multiple evaluation in the same animal, for instance, the use of a representative body part or the use of less invasive methods, such as dual-energy X-ray absorptiometry.

For future goat energy system, modeling should be a fundamental tool to integrating the aggregated knowledge regarding energy use in goats, fulfilling the main purpose of enhancing our ability for predicting and improving animal performance. As CNES was successfully evaluated by farmers and the beef cattle industry, models developed for goats should also be evaluated in real-world condition, allowing continuous adjustments in the models.

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