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Biomass Energy Flow Assessment Using The Material Flow Analysis (MFA) Method For Livestock Production System

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Abstract: This paper assesses energy flow of biomass sources in animal production system for the Terengganu in year of 2011. The potential energy production of livestock waste is investigated by using Material Flow Analysis (MFA) approach. Based on the findings, 545 kt head per year of total unused biomass from animal dung could contribute to 374 PJ/year of energy which equals to 10.4×10^{10} kWh of electricity generation. The regions of Besut appear to be good candidate for biomass conversion technologies development whereas cattle and poultry pools are recognised as the best contributor for energy production.

Key words: Material Flow Analysis (MFA) · Biomass energy · Terengganu · Livestock waste

INTRODUCTION

Biomass of renewable energy resources is significant in contributing towards sustainable development in future. In Kyoto Protocol held in 1997 in Japan, the level use of biomass energy is proposed to be in average reduction of 5.2% in GHG emissions between 2008 and 2012 with the introduction of Clean Development Mechanisms (CDM) for action plan [1]. Currently, biomass energy accounts for about 10 to 15 percent of total primary energy consumption of global consumption [2, 3]. No doubt, the interest in biomass consumption has escalated during last decades due to benefit in preventing for global warming, energy crisis and environmental pollution.

In Malaysia, the subject of biomass energy potential has very closely attracted government in formulated several policy and plans. For example, in May 2001, Malaysia government has launching the Small Renewable Energy Power Program (SREP) to encourage the usage of renewable energy [4]. Others in line with this are Biomass Grid-Connected Power Generation and Co-Generation (Biogen), Building Energy Efficiency Programme (BEEP), Green Building Index (GBI) and Malaysia Building Integrated Photovoltaic Technology Application (MBIPV) [5]. In terms of energy policy, Malaysia was formulated several strategy including Five-Fuel Diversification in 8th and 9th Malaysia Plan, Energy Efficiency in Commercial Buildings (MS1525) and Kyoto Protocol [6].

Terengganu represents one of the state in Malaysia endowed with great biomass resources. Almost 98 percent of cultivated biomass in agriculture system have not been fully explored and utilized [7]. Thus, a number of incentives and work plan has been framed and programmed by the state government to improve this situation. In 2015, a 60,000 metric tonne bioisobutanol production plant will be constructed in Kertih, Terengganu, that will utilized around 10.5 million tonnes of wood chips each year as their biomass input resource [8]. Therefore, it is becoming critical to promote the bioenergy use with an understanding that the conflict of interest exists in biomass resources issues. Livestock sector is one of the biomass system always being ignored for energy purpose, nevertheless is an important step forward in this study.

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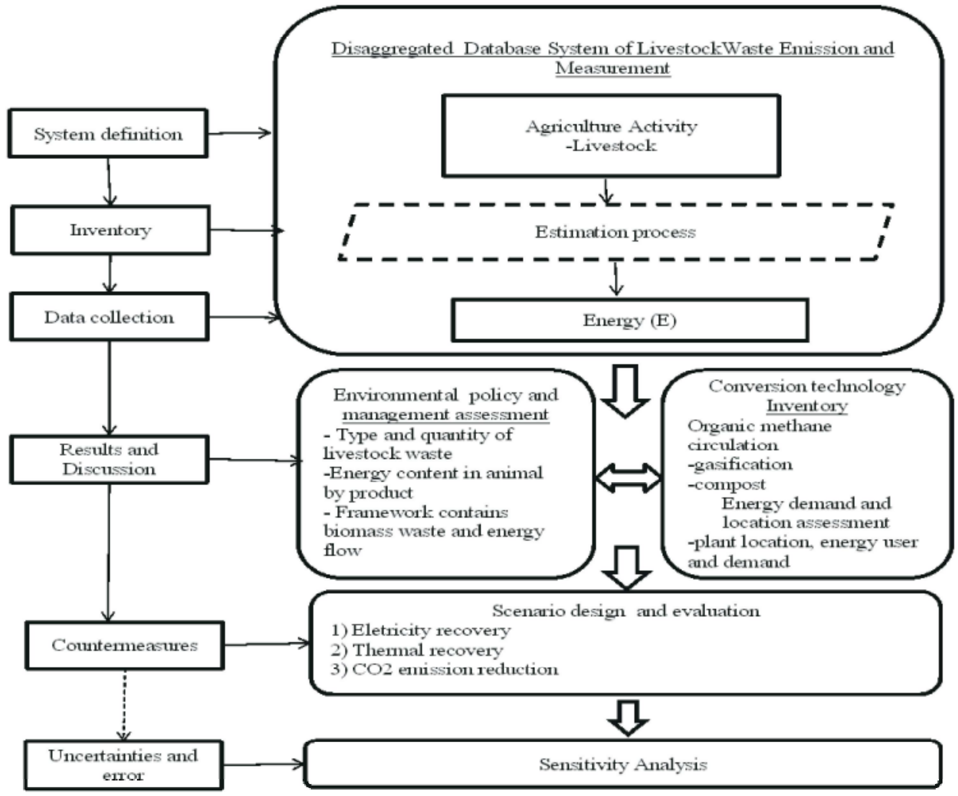

Fig. 1: Research framework for livestock production system

This study examined the energy flow associated with livestock production system because of its potential demand in the future. Biomass energy from livestock waste products is a renewable bioenergy because the emission of greenhouse gas (GHG) is low [9-12]. However the sustainable transformation for livestock wastes as bio-energy feedstock into fuel and electricity generation have not been described in intuitive and quantitative of single model prospect in Malaysia. In order to study that, the Material Flow Analysis (MFA) has been used to investigate the behavior of energy in animal production looking into starting from animal resource assessment to get hot spots factors for bioenergy system suggestion in selected region.

Methodology: This research was conducted as outlined in Figure 1. In general, the research approach can be divided into three main stages, namely: goals and system definitions, inventory and modelling and interpretation.

System Definition: In the first stage, work conducted is to identify the energy balance in the animal production cycle in the state of Terengganu. Boundaries of the animal system selected is seven districts of Hulu Terengganu, Marang, Dungun, Setiu, Besut, Kuala Terengganu and Kemaman. The calculation unit for livestock waste is defined in kilo tons/year (ktons per year) and energy units are peta joule/year (PJ per year). The time scale is set in the year 2011. There are four inputs identified which are animal bedding, animal imports, animal grazing and feedstuff from feedmill. Five energy flow output is exported animal, manure, emission CH_4 of enteric fermentation, emission CH_4 of manure management and livestock wastewater and runoff and animal by-product. However, estimation for animal respiration and animal metabolism will not be determined in this study.

Inventory and Modelling: Stage two involves gathering livestock statistic information obtained from Terengganu Veterinary Services Department. In addition, a series of site visits to livestock and poultry farms, animal slaughterhouse center and poultry breeding center to get a clearer picture regarding the management of livestock waste was conducted. For data analysis and processing, two methods were used, namely Stan software and Microsoft Excel. For this study, the definition of biomass material in the context of animals are categorized into four sources namely, 1) Waste from feedlots and abattoirs, 2) Animal manure, 3) Dead animals, 4) Waste from slaughtering processes (such as carcass, bone, oval, feather, skins and meat processing, etc.) Quantification process in this study is based on static modelling. According to [13], static modelling in MFA can explain the development of a system consistent with the mathematical structure of different flows and stock.

Interpretation: The final stage was to analyse the results obtained and to present the mass flow of biomass energy in a simulation framework of the MFA model. In this case, there was only one sector of the agricultural system which focused on biomass energy flow in animal production systems. Proposals for the development of alternative energy conversion technologies are also discussed.

Mathematical and Formulation of MFA Models: Simple mathematical formulation for energy flow estimation in animal husbandry is shown in equation 1, equation 2, equation 2a and equation 2b.

Manure Estimation from Livestock: Calculation for livestock manure emissions based on Sibbesen and Runge-Metzger method [14] and Bhattacharya [15] is simplied as:

$$E_{la} = (Q_m / f_{ca}) * C_{la} \quad (1)$$

Where,
E_{la} = Energy in live animals removed from the system agriculture
Q_m = Quantity of the meat based on dressed carcasses excluding offal and slaughter fat
F_{ca} = Carcass fraction (comparable to dressing % or the mean weight of dressed carcasses relative to that of live animals)
C_{la} = mean E concentration of live animals (C_{la} = Fea*Cea + Fgi* Cgi + Fu*Cu)
Fea = the mean weight of empty animal
Fgi = the mean weight of gastrointestinal content
Fu = the mean weight of urine
Cea = the mean E concentration in empty animal
Cgi = the mean E concentration in gastrointestinal
Cu = the mean E concentration in urine

By using the data on energy in animal products and distribution coefficients, the amount of E in manure and fodder are re-calculated by using the equation:

$$E\ manure = (E_{rem}/E_a) * E_e$$

Where,
E_a= Distribution of fodder E on animal
E_e= Distribution of fodder E on excreta

Methane Emissions Estimation from Livestock: Calculation of methane from livestock emission factors based on the standards at Tier 1 and Tier 2 provided by the IPCC [16]. Thus, in this study, the two formulas used in the enteric fermentation and manure management are shown in equation 2, equation 2a and 2b.

$$\text{Total methane emission of livestock} = CH_{4\,Enteric} + CH4_{Manure} \quad (2)$$

Methane Estimation from Enteric Fermentation (EF):

$$CH_{4Enteric} = \sum \frac{(EF(T) \times N(T))}{10^6} \quad (2a)$$

where, methane emission is in Gg/year:
EF(T) = Emission factor for the defined livestock population (kg/head/year)
N(T) = Number of head of livestock species T in country
T = Species of livestock

Methane Estimation from Manure Management (MM):

$$CH_{4manure} = \sum \frac{EF(T) \times N(T))}{10^6} \quad (2b)$$

where:
$CH_{4Manure}$ = Methane emissions from manure management (Gg CH4/year)
EF(T)= Emission factor for a defined livestock population (kg/head/ day)
N(T)= Number of head of livestock species T in country
T= Species of livestock

RESULTS AND DISCUSSION

Study Area: Terengganu is situated in north-eastern Peninsular Malaysia with total population of 1,015,776 in 2010. The country borders with northwest by Kelantan, the southwest by Pahang and the east by the Laut China Selatan. Terengganu is located between 4 □ 45 □ and 103 □ 0 □ E on the atlas map. The total land area of Terengganu is 13,035 km^2 with total land use for agriculture sector is 21.6% (280,063 ha) of 1.29 million hectares in 2010 [17].

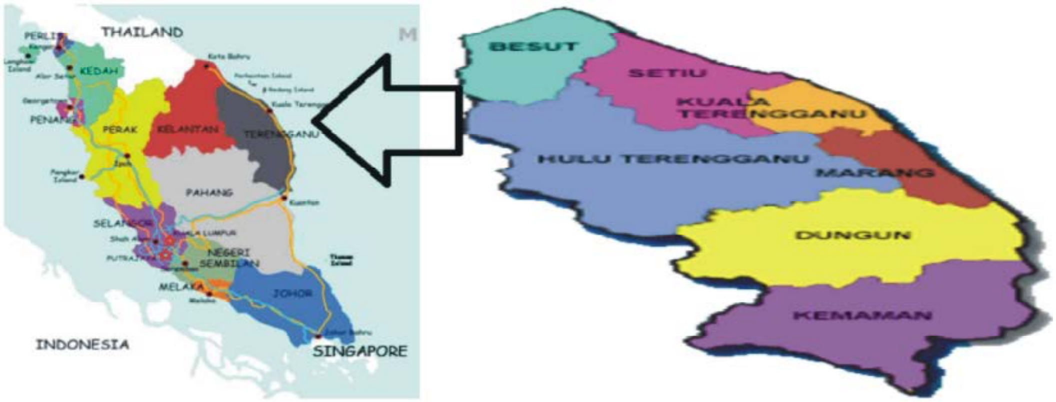

Fig. 2: Location of case study, Terengganu State.

Table 1: Emission coefficient factor and methane emissions for EF and MM in 2011

Livestock	EF coefficient factor	EF emission	MM coefficient factor	MM emission
Buffalo	55.0	0.57	2.0	0.00
Cattle	68.0	6.54	31.0	2.98
Goat	5.00	0.17	0.22	0.00
Sheep	5.00	0.01	0.20	0.00
Poultry	0.02	0.08	0.02	0.08
Sum		7.37		3.06

Source: IPCC (2007), USEPA (2004)

In Terengganu, the contribution of livestock to Terengganu Gross Domestic Product (GDP), including agriculture, forestry and fisheries is around 9.7% (around 1,423 million RM) as of 2010. Animal production sector is considered as of the major corner stones for agricultural economy which provides livelihoods for about 20% of the population and employs about 6% of the labor force. The livestock industry is primarily comprised of the buffalo, cattle and goats, sheep and poultry with the population of 10.5, 96.3, 35.1, 3.3 and 3575 thousand head respectively in 2011. However, the amount for pigs population is not available due to the rearing of pigs in Terengganu region is not allowed as being regulated by the state of Terengganu [18]. Terengganu map is illustrated in Figure 2.

Methane Emissions: Table 1 shows the coefficient factor for enteric fermentation (EF) and manure management (MM) with methane emissions results for each category of livestock in Terengganu. The total methane emission of livestock was 10.43 Gg per year, with methane emissions from EF account for 71% (7.37 Gg per year) and methane emissions from MM accounts for 29% (3.1 Gg per year). This corresponding value in energy unit was estimated to be 0.03 PJ for EF and 0.01 PJ for MM.

As shown in Table 1, methane emission of cattle contributed the highest value for energy discharged to the environment with 96% (9.5 Gg per year), among other livestock. Several assumption based on Terengganu scenario can be made where is; 1) In recent years, the Terengganu state supports cattle rearing in large and medium feedlot farm in terms of financial loan and agriculture land use, fertilizer and feedstuff subsidies which have contributed to large cattle production yields [19], 2). Minor factors which influence to methane released into atmosphere are cattle body size, large appetites, feed intake body, digestibility of feeds, feed processing with lipids, feed efficiency, quality of diets, level of stress and genetics [20-23].

Manure Generation: The calculation results of manure discharged in Terengganu, which explained the differences in the material flow pattern, can be described in two factors namely boundary of the system and categories of livestock. The values of livestock and poultry manure generation in each district in Terengganu are illustrated in Figure 3. The dung coefficient (in kg/head/day) used for each animal in average range was 10.5 (buffalo), 9.4 (cattle), 3.6 (goat and sheep) and 0.1 (poultry) [24-27]. On the other hand, as shown in

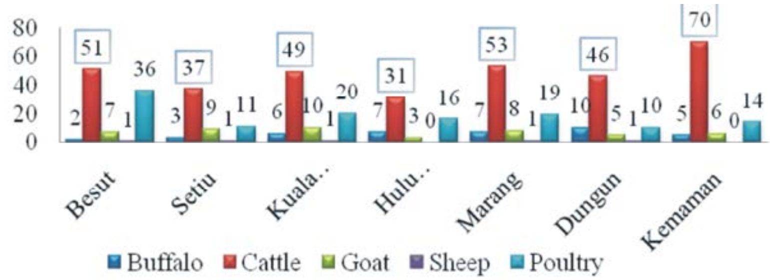

Fig. 3: Livestock and poultry manure generation by district in Terengganu (in 10^3 dry ton)

Table 2: Animal manure characteristics in biomass energy estimation

Species	Dung production (kg head^{-1} day^{-1})	Recoverable fraction	Volatile Solid fraction (kg VS kg^{-1} DM)	Biogas Yield M3 kg^{-1} VS
Buffalo	10.5	0.50	0.80	0.43
Cattle	9.4	0.60	0.93	0.31
Goat	3.6	0.33	0.60	0.49
Sheep	3.6	0.33	0.60	0.49
Poultry	0.1	1.00	0.47	0.28

Source: Sopian *et al.,* (2005), Medina (1980), Bhattacharya *et al.,* (1997), Devendra *et al.,* (1997), Essel and Charles (1997), Shinya and Matsumura, (2008) and Martin, (2010).

Figure 3, the biggest share in animal manure discharged came from the cattle with 60% (329 kt/year), followed by poultry, 23% (125 kt/year) and the rest 17% was total amount of buffalo, goat and sheep (91 kt/year). The enormous quantity of cattle and poultry manure (chickens and ducks) discharged corresponded to increase in stock population in every year. Referring to Terengganu Animal Census Report [17], the value of livestock production from poultry species showed the highest value in three consecutive years with 4,549,020 (2008), 3,117,669 species (2009) and 3,770,765 (2010) [18].

Results found in this study highlighted some important factors particularly with respect to practices and livestock management, availability of biomass resources, environmental pollution, biomass conversion technology options, policy and legislation and other issues. For instance, this study has revealed that the substantial amount of manure generation, which was 545 kt/ year in total in Terengganu, might offer a significant biomass resource for energy supply in Terengganu and might suggest bioenergy plant location, if competitive demand and use of energy in the future are taken into account.

Biomass Energy Potential for Livestock Production: The estimation for biomass energy potential is based on the values of manures characteristics used as presented in Table 2. The overall amount of biomass energy potential of animals for each region is around of 374 PJ/ year. This value is equal to 10.4 × 10^{10} kWh of electricity generation with a biogas potential of 17.9×10^6 m^3. Besut district represents a significant potential location for biogas implementation project as it showed the highest density of biomass energy which is estimated at 18% (66.6 PJ per year). Meanwhile, the estimates of biomass energy showed that, out of 3.58 million livestock population in Terengganu in 2011, about 31% (114 PJ per year) derived from poultry sector. Therefore, theoretically, as supported by findings in the research carried out by Othman [28], there is a huge potential to use poultry dung to generate renewable energy in Malaysia via biogas technology adaption. According to Pimentel *et al.* [29], broiler-chicken production was the most energy-efficient in case of livestock production, with 1 kcal of broiler protein produced with an input of 4 kcal of fossil energy.

Energy Flows Balance in Livestock Production System: The calibrated MFA model for biomass energy balance in livestock production is depicted in Table 3. The animal system is divided into two main parts:

Inputs: Biomass energy flow from Animal Import (A+), Animal Bedding (B+), Animal Grazing (C+), Feedstuff from Feed mill (D+) and Animal Respiration (E+).

Outputs: Biomass energy flow from Animal Import (A+), manure (b), methane emissions (c) livestock runoff (d) and wastewater (e).

Table 3: Balance sheet for energy flow in Livestock Production System in Terengganu, 2011

Code/Flow	Operator	Description	Units	Value
		Input		
A_{1+}		Animal import	PJ/year	199.42
A_{2+}	(+)	Animal by-product	PJ/year	2.67
A+	(=)	Total animal import	PJ/year	202.09
B_{1+}		Rice straw	PJ/year	0.79
B+	(=)	Animal bedding	PJ/year	0.79
C_{1a+}		Pasture uptake of cattle/buffalo	PJ/year	8754.00
C_{1b+}	(+)	Pasture uptake of goat/sheep	PJ/year	344.00
C_{2+}	(+)	Corn stubble + Cereal stubble+ etc	PJ/year	0.50
C+	(=)	Animal grazing	PJ/year	9099.00
D_{1+}		Cattle feedlot feedstuff	PJ/year	1.70
D_{2+}	(+)	Goat feedlot feedstuff	PJ/year	0.01
D_{3+}	(+)	Poultry feedstuff	PJ/year	6.51
D+	(=)	Feedstuff from feedmill	PJ/year	8.21
E+		Energy input from animal metabolism	PJ/year	Not determined
LV $E+_{input}$		Total Energy input	PJ/year	
	(=)	(A+)+ (B+) + (C+) + (D+) + (E+)		9310.10
		Output		
A_{1-}		Animal export	PJ/year	2.36
A_{2-}	(+)	Animal by-product	PJ/year	0.22
A-	(=)	Total animal export	PJ/year	2.58
B_{1-}		Cattle manure	PJ/year	202.40
B_{2-}	(+)	Buffalo manure	PJ/year	26.10
B_{3-}	(+)	Sheep and Goat manure	PJ/year	31.50
B_{4-}	(+)	Poultry manure	PJ/year	113.60
B-	(=)	Total animal manure	PJ/year	373.60
C-	(=)	Animal by-product		0.22
D_{1-}		Enteric fermentation	PJ/year	0.03
D_2	(+)	Manure management	PJ/year	0.01
D-	(=)	Total methane emmission of animal	PJ/year	0.04
E_{1-}		Pig manure	PJ/year	NA
E-	(=)	wastewater (includes urine)	PJ/year	0.00
F-		Livestock feedlot (runoff)	PJ/year	301.00
LV $E-_{output}$		Total Energy input	PJ/year	
	(=)	(A-)+ (B-) + (C-) + (D-) + (E-)	PJ/year	677.44

As demonstrated in Table 3 the energy balance accumulated in the livestock system is 200 PJ/year, which was quantified from the sum of animal import minus animal export. This result can be defined as unknown amount (losses) of energy flow that may be influenced by the factor of stocks and error in data allocation. However, this issue is not discussed in this study. According to Brunner and Rechberger [30], there are always conflicts in MFA, in case of input, output and changes in stocks of processes that do not match and balance.

Figure 4 shows the MFA model for regional energy metabolism of livestock production in Terengganu. In livestock production system, the dominant input of energy flow contributor is animal grazing from fodder production, which is responsible for 98% (9099 PJ/year) of energy flow followed by 2% (202 PJ/year) animal to be processed inside the region (imported). Meanwhile, less than 1 percent was calculated from the sum of feedstuff from feed mill, animal bedding and animal respiration.

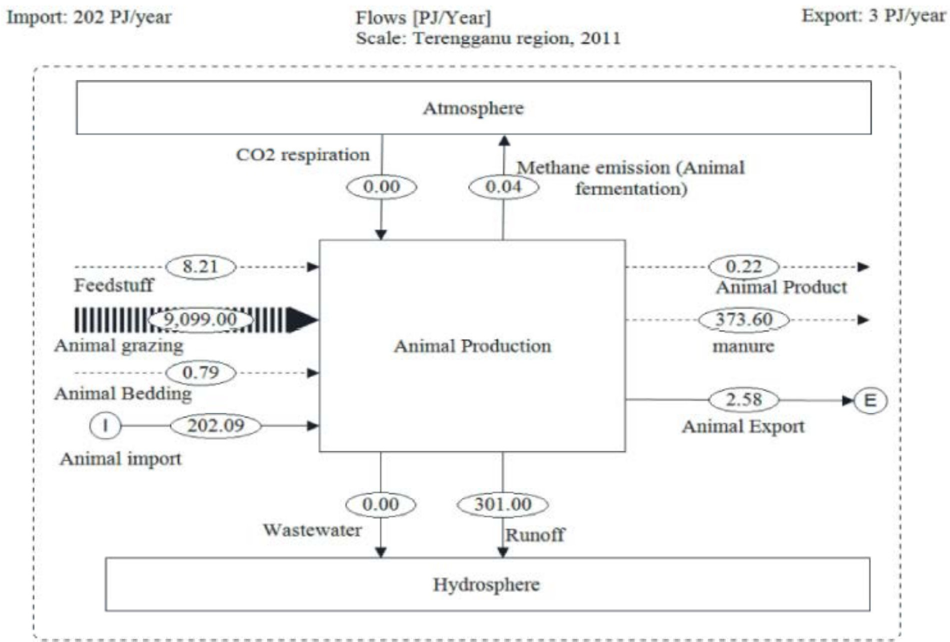

Fig. 4: The MFA for energy flow in livestock production system

Studies have indicated that there is very high potential to produce energy, from fodder uptake by livestock sector, but at present none of these wastes are used to produce bioenergy in this region. According to DVS [18], per capita consumption of livestock product in Malaysia are beef (5.71 kg), Pork (8.00 kg), Poultry Meat (39,19 kg) Poultry eggs (316 gm/egg) and milk (59.86 kg). In term of second input flow of energy, animal import, about 75% of animal population is imported into the region. Thus, there is a large consumer growth rate demand especially due to changing in living standards, market demand, kind of feed and level of nutrition. According to Bouwman [31], dietary energy output of livestock is calculated as metabolisable energy content of the product that is intended for human consumption.

The output energy flow of animal system is summed up to be 677 PJ/year in 2011. The major output flow of energy came from dung animal manure with 55% (374 PJ/year). The second largest flow of energy is animal wastewater, which account for 301 PJ/year or 44%. The rest output flow of energy was altogether about 1% (3 PJ/year) from animal import, methane emissions and livestock runoff. According to Nusbaum [32], several factors that may have influenced the total output energy are weather, yield, price and technology.

In summary, this study found that energy flow input is 93% higher that energy flow output. Because of the minimum efficiency activities in animal waste recycling, composting and dung pre-treatment, plus legislation barriers, lack of new conversion technologies and information, was responsible for low environmental and economic merit in renewable energy contexts.

Sensitivy Analysis: The main goal of sensitivity analysis is to determine the influence on the flow of energy when parameters increased or decreased in value into the framework of the MFA model. Results are reported as a sensitivity analysis of the effects of parameter changes on the average measurement error is selected as done in the calibration criteria. Moreover, the most significant error in this study is weaknesses in comprehensive field data in the energy conversion factor in selected region. In addition, in Terengganu region, limited number of research has been conducted on energy flow in livestock system, plus livestock data is not well documented. Coefficient used is based on other countries, particularly in Asia.

CONCLUSION

In this study, the MFA has been used as a tool to study the potential generation of energy from livestock production systems. Simulation MFA model has been developed and accounting sheet have been carried out to establish flow of energy balance in the region.

The picture as shown in Figure 4 for the production process of livestock energy have been identified. From the estimation, the average biomass energy generated from livestock waste products in Terengganu can be improved by 89 percent compared to the current system. Findings from the MFA study may be used by the authorities to improve current operation and to increase the total production of animal products, promote biomass generation, reduce pollutant emission released into the environment and to propose the concept of bio-energy system to be built in Terengganu region.

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