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Mitigation Scenario of Beef Cattle Greenhouse Gas Emission In Developing Country: A System Dynamic Approach

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Abstract

Ever increasing beef demand and government desire to fulfill it has built stress on beef production system. The system then tries to increase it production capacity by increasing cattle population. This leads to the increment of greenhouse gas emission. Specifically, cattle dominate 65% of greenhouse gas emission from agricultural activity. With the densest beef cattle population, East Java have the biggest amount of green house gas emission from beef cattle in Indonesia. The purpose of the research is to find out what mitigation is the most effective to reduce this emission. A model of green house gas emission from beef cattle developed using system dynamic approach. It includes stages such as problem articulation, development of dynamic hypothesis, simulation model formulation, model validation and scemario development. Secondary data from previous researches are used in the model development. Several mitigation scenarios then developed and applied to the model. According to the model developed, emission can be reduced by implementing feed additive. Natural feed additive is used on the model instead of syntetic chemical. This mitigation scenario is able to reduce overal greenhouse gas emission by 4% by adding 15% of Acacia mangnium leaves to the feed. Model and scenatio can be used by stakeholders as reference to mitigate green house gas emission from beef cattle.

Keywords: *System dynamics, Modelling, Environment Dynamics, Greenhouse gas emission, Beef cattle*

1. Introduction

Beef consumption demand is expected to increase for the following years due to population increase, economy development and public awareness of the benefits of consuming it [1]. Each person consumes 2,2 kilograms of beef in a year and it is predicted to increase up to 2,412 kilograms of beef in 2029 [2]. This condition puts so much stress on the cattle beef production system to fulfil the continuously increasing demand. Government has done several programs to support the system. The result can be seen from the increasing population of beef cattle from 16,43 million cattle in 2017 to 18,05 in 2021 [3] [1].

East Java has the densest population of beef cattle in Indonesia. Around 25% of the beef cattle population in Indonesia, is located in East Java. In 2020, it has over 4,93 million cattle live in it [4]. The number tends to increase each year as can be seen on figure 1. This makes East Java to be able to produce up to 93 thousand tons of beef cattle and enough to fulfil its own population demand [5] [2] [4]. Figure 1 shows the graphic of the beef population in East Java.

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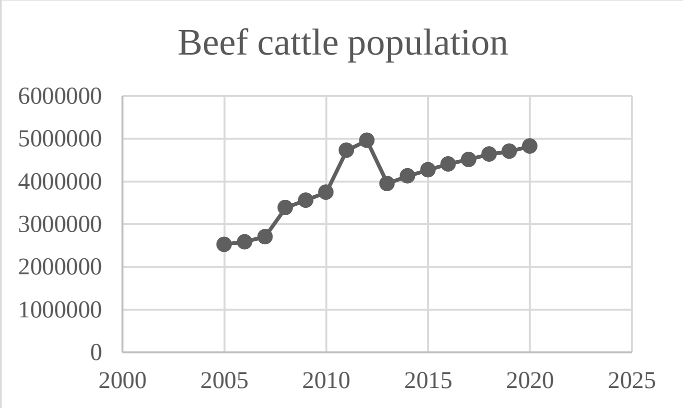

Figure 1. East Java Beef Cattle Population

Nevertheless, this increasing cattle population leads to another problem. It is related to the greenhouse gas emission emitted by cattle in the form of CH_4, N_2O, and CO_2. It contributes up to 65% of greenhouse gas emission from livestock industry [6] [7]. These gases are useful to keep the earth temperature warm, but it increase would lead to global warming and climate change [8]. Then the climate change would reduce the productivity of the livestock [9]. Thus mitigation is needed to reduce the negative impact from these greenhouse gas emitted from beef cattle. Increasing human population, increasing beef demand, increasing cattle population, and its increasing emissions seem to be related.

The topic of how to mitigate the greenhouse gas emission from cattle has been long discussed. There are many proposed methods such as Improving diets by increasing feed quality, methane decreasing substances feed supplementation and improving manure management by implementing biogas digester are among other mitigation methods than can be chosen [9] [10]. Sterman also proposed reduction of food waste and less meat lifestyle to mitigate this emission during the Climate Action Simulation run at MIT.

However, the amount of greenhouse gas emission from cattle may differs due to the characteristics of the area. Areas with warm and wet characteristic tend to emit more manure management gas than cool and dry areas. The difference of manure management system used in the area also affect the emission [11]. So the question of this research is "Which is the best way to mitigate the greenhouse gas emission from beef cattle for a specific area?"

To answer that question, this study develops a model of the greenhouse gas emission from beef cattle and determine which one is the most effective. East Java province of Indonesia is used as it has densest beef cattle population in Indonesia [4]. A model developed using system dynamics approach and validated by data from *Badan Pusat Statistik* (BPS) and international organization publication. Scenario of each mitigation then applied to the model to identify the impact. This paper is organized to several section. Section 2 describes a review of previous research regarding greenhouse gas emission and system dynamics on beef cattle. The method of this study is in section 3. Section 4 discuss the results of this study. The last section describes conclusions and recommendation for further research.

As ruminants, cattle emit CH_4 from its digestive process. It involves fermentation activity with the help of rumen microbes. These microbes then produces CH_4 which afterward excreted through burps, breaths, and farts [12]. According to Munawaroh and Widiawati, the emission is affected by the gross energy intake (GEI), the methane conversion factor of the feed (Y_m) and the feed digestible energi (DE) [12] [11]. CH_4 gas also comes from cattles feces. Accroding to Munawaroh and IPCC document, it emission is influenced by volatile solids excretion (VS) and manure management used. VS itself is affected by DE and ASH content of the feed (ASH) and the cattle GEI [11] [13]. Another type of greenhouse gas is N_2O. Unlike CH_4, this gas is not emitted from its enteric digestion process. Yet it is due to nitrification and denitrification process undergo in cattle's feces. The amount of N_2O produced is affected by the body wight and the type of manure management used [11] [13].

Due to the gases global warming potential, mitigation need to be undertaken to reduce the impact to the environment [14]. Mitigation can be done both on the enteric emission and on the manure emission. Enteric CH_4 emission can be reduced by improving nutrition of the feed or by adding aditives. Research by Sugiarto and Nurhayati stated that nutrition of the feed can be improved by adding concentrates and leguminose [14] [15]. Previously, Lovett and Martin reported that adding concentrates could reduce CH_4 emission from enteric fermentation [16] [17]. While adding leguminose to cattle feed could improve the nutrition of the feed subsequently reduce its enteric CH_4 emission [18]. Enteric CH_4 can also be reduced by using feed supplementation. According to a review by Llonch, chemical inhibitor, nitrate and ionophores, and lipids inclusion are some methods that have been suggested to reduce CH_4 emission [19]. Those methods can achieve large CH_4 emission reduction. But this reduction comes with risk. For example, chemical inhibitors such as bromochloromethane (BCM), 2-bromo-ethane sulphonates (BES) and chloroform that could reduce 25% to 95% of direct CH_4 emission but may risk the health of animal itself and human who consumes it due to toxicity of the chemical compound [19]. As an alternatives, natural sources can be used as feed supplementation. Saponins that is contained in some tropical plants have been found to surpress CH_4 production. Some plants containing high level of flavonoids could also decrease CH_4 production. Similarly, tannins have also been found with the same effect. Some of the plants that can be the source of that secondary metabolites are *terminalia chebula* and *acacia mangnium* [20] [21]. Patra stated that the methanol extract of *T. chebula* has antimethanogenic activity [21]. The more recent study stated that adding *A. Mangnium* to cattle's feed is could potentially reduce cattle's enteric emission [20].

System dynamic is a modelling methodology that is developed by Jay W. Forester, a professor from MIT. It can be used to model systems by identifying factors and their relations. Tools such as causal loop diagram (CLD) and data flow diagram (DFD) are utilized to represent the system which is modelled [22]. It iterative and informative characteristics make it a helpfull methodology for stakeholders to fetch decision regarding complex systems [23] [24]. Systems such as beef production, paddy production, soybean production healthcare facility, urban transportation has been modelled to solve its ows specific problems. Those researches result in screnarios that can be adopted by related stakeholders. Knowing this methodology advantages, this study then tries to model the beef cattle greenhouse gas emission that can be used to model several mitigation methods offered by previous researches.

2. Research Methodology

The following are stages of this study :

2.1. Problem Articulation

The first stage is done to comprehend the issue to conduct the study. Any information rearding the issue are are obtained from different sources such as papers, proceedings, organization published data, and also goverment's official websites. Good comprehension regarding the issue will help to identify the key factors which have significant role.

2.2. Dynamic Hypothesis Development

Dynamic hypothesis then developed on the basis of the problem articulated in the previous stage. This hypothesis will be the basis of the model development. It contains the concept of how the system in discussion works. System dynamics uses CLD to depict the variables involved and the relationships between them.

2.3. Model Formulation

The system of related issue then modelled so then it can be simulated. The simulation model is formed by using equations. The equations are formulated based on the related literature to follow the real world behaviour of the system.

2.4. Testing

The simulation model then tested to find out whether the simulation model satisfies the real world situation. Mean comparrison and error variance are statistical analysis used to validate the simulation model. The system is valid when mean comparison is less than 5% and error variance is less than 30%.

2.5. Testing

The formulated model in the previous then developed to several different scenarios to find the best scenario that fits the objective of the study. Scenarios are formulated by implementing several different solution to the model. The model adapts by changing its factors value or even its structure. These scenarios then validated to make sure that each of them is suitable for the issue. These stages can be depicted as can be seen in figure 2.

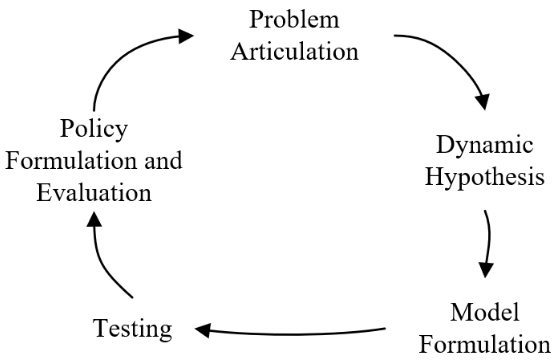

Figure 2. System dynamics methodology

3. Result and Discussion

The model development result will be discussed in this chapter.

3.1. Dynamic Hypothesis

Stages in system dynamics model development include developing dynamic hypothesis that explain the theory of how the problem emerges. Beef production system is under stress to fulfill ever increasing beef demand [3]. And because beef is produced by cattle slauhgtering, the cattle population need to be increased to [4]. But the increase in population also means the increase in green house gas emisson [11]. Incrase in green house gas emission will affect on the environment average temperature. High environment temperature can affect negatively to husbandry industries production including beef production [8]. The key factors of the issues identified in this study are the cattle huge population and the amount of greenhouse gas produced from each of them.

As we know, Indonesian government tries to achieve self animal food sovereignty[1]. Lowering the total population of beef cattle population is not a suitable way. Since it will affect the amount of beef it can produce. So the suitable way is by lowering the emission from each cattle. This can be done by modifiying emission from enteric and its manure. A CLD of this dynamic hypotheis can be seen on figure 3.

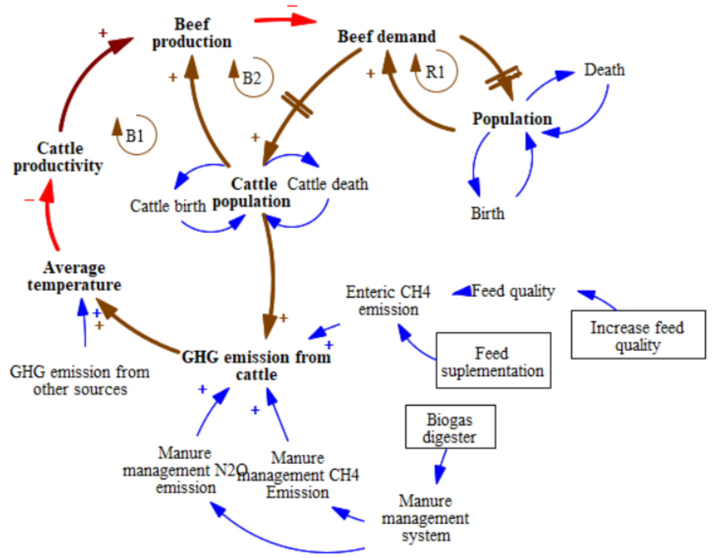

Figure 3. System dynamics methodology

3.2. Simulation Model

To be able to conduct a simulation, a simulation model need to be developed based on the dynamic hypothesis developed. The model's simulation can be divided into several different sub models to ease the model development

1) East Java Population

The total human population in East Java affects the cattle population through its demand of beef consumption. Cattle population needs to be in sufficient amount to be able to produce beef as many as needed. According to data published from BPS, population in East Jawa increased from 36,48 million in 2005 to 38,76 million people. This sub model is developed to follow this data increment.

2) East Java Beef Cattle Population

This sub model is developed to describe and simulate the beef cattle population in East Java. The total population of beef cattle in this sub model is affected by the births and deaths of beef cattle [25]. The sub model developed to be able to replicate the beef cattle population data published by BPS that show population increment from 2,52 million in 2005 up to 4,82 million in 2020 [4].

3) Enteric CH_4 emission

Beef cattle emit CH_4 from its digestion process. The amount of CH_4 emitted by a cattle is affected by several factors such as its age, gross energy intake, and feed quality. This individual emission amount then multiplied by its population following the population structure used in previous research which can be seen in table 1 [12].

4) Manure Management CH_4 emission

This sub model describes how CH_4 emitted from beef cattle manure management. According to IPCC calculation, the amount of emission is affected by its feed quality, age, and the type of manure management used [11]. Due to limited data regarding manure management usage in East Java, the model developed by following default values published in IPCC document as shown on table 2.

5) Manure Management N_2O emission

The next sub model describes the emission of N_2O from manure management. Its emission affected by cattle's age, body weight, and the type of manure management usage. Similar to the previous model, this model uses default values of manure management usage published in IPCC.

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Table 1. Beef cattle population structure

Age group	Population fraction (%)	Alive weight (kg)
Weaning	19.30	63
Off weaning	25.85	134
Young	18.15	286
Adult	26.89	400
Imports	9.81	500

Table 2. Manure management system usage

Manure management system	Usage(%)
Lagoon	0
Liquid/slurry	1
Solid storage	21
Drylot	29
Pasture/range/paddock	38
Daily spread	0
Digester	0
Burned for fuel	0.011

3.3. Policy Formulation and Evaluation

There are three scenarios resulted in this study.

1) Biogas Digester Scenario

This scenario modifies the model by replacing previously used default values of manure management system usage from IPCC documents. The usage of solid storage in the previous model is completely replaced by biogas digester. The effect of this scenario is reduced amount of CH_4 because the gas is contained and can be used for other purposes as can be seen on figure 4. This manure management change can also reduce the N_2O emission since it has smaller emission factor than solid storage [11] (figure 5). Up to 28 % reduction of CH_4 and 0,09% of N_2O emission can be achieved by this scenario. Previous research by Herawati stated that biogas digester can help to overcome global warming issue while providing economy potential to surrounding communities [26]. An expert in BPPT also supporting this statement [27].

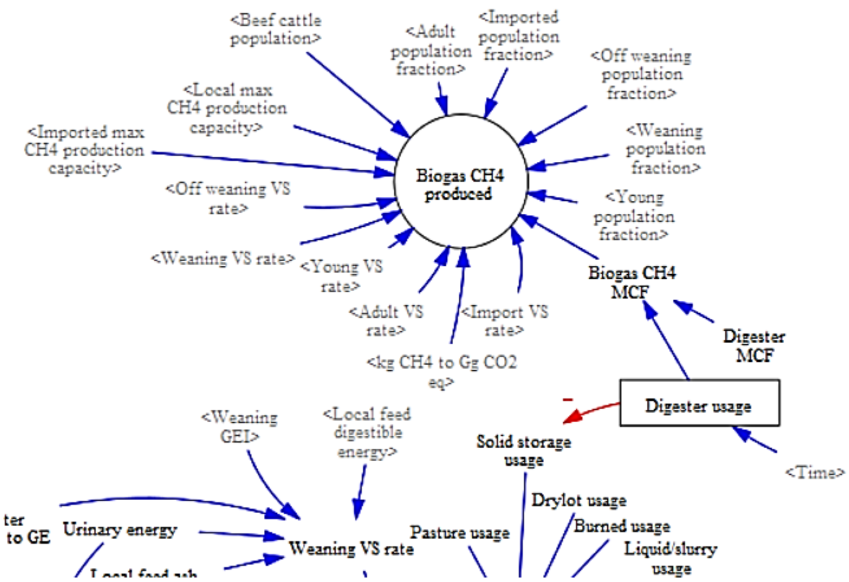

Figure 4. Digester Scenario Effect on CH_4 Emission

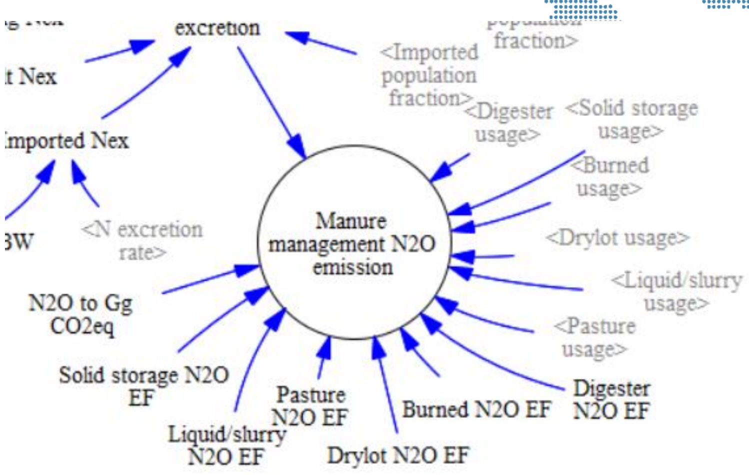

Figure 5. Digester Scenario Effect on N_2O Emission

2) Feed Additive Supplementation

The second scenario involves adding substances that can reduce enteric CH_4 emission. Natural source is used instead of synthetically made chemical additives because it is safer [19]. The addition of *Acacia Mangnium* can be used to reduce enteric CH_4 emission as can be seen on figure 6. It reduction rate follows the percentage of *Acacia Mangnium* in the feed. The model is modified by introducing the percentage of reduction if the feed is mixed it by 15%. 16,2% of enteric CH_4 emission can be reduced by this scenario. This scenario is validated based on Santoso's research of using *Acacia Mangnium* to reduce methane emission [20]. The same effect also showed by Mahardika in his research [28].

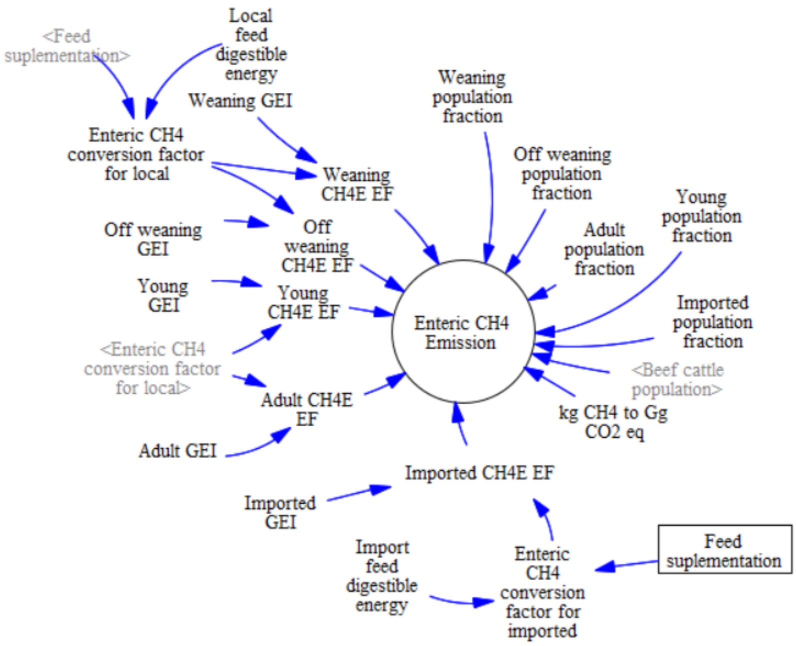

Figure 6. Feed Supplementation Effect on Enteric CH_4 Emission

3) Feed Quality Improvement

The last scenario is by increasing the digestible energy (DE) of the feed. Generally, beef cattle in Indonesia are fed by low quality feed from agricultural crop residues which has low value of DE. However, it can be increased by mixing forages or crop residues with concentrates as shown by figure 7. Previous researches also stated that by combining forages and concentrates can increase the feed DE. According to the calculation formula in IPCC document, increased DE value will reduce cattle's enteric CH_4 emission factor (figure 7). To follow this scenario, modification to the model is done by increasing the value of DE of the feed. Simulation on this scenario shows that the enteric CH_4 emission can be reduced up to 9%.

The accumulation of CH_4 and N_2O reduced by each scenario is compared to find which is the most effective. The result shows that the first scenario can reduce up to 2% of the emission. The second scenario is able to reduce up to 4%. The last scenario can reduce up to 3%. Table 3 shows the reduction comparison of the screnarios created. It can be seen that scenario 2 is the most effective to reduce the overall greenhouse gas emission.

4. Conclusion

Green house gas emission from beef cattle can be modelled to follow characteristics of an area. Climate characteristics can affect how much gasses a cattle produce each year. Population characteristics also affect the calculation of the overall green house gas emission. Due to the dense population of beef cattle and its impact on environment, mitigation steps need to be undertaken. Natural methanogenesis inhibitor can bee added to cattle's feed to reduce this green house gas emission. But due to the dynamic characteristics of the area, the model can be developed to accomodate the changes.

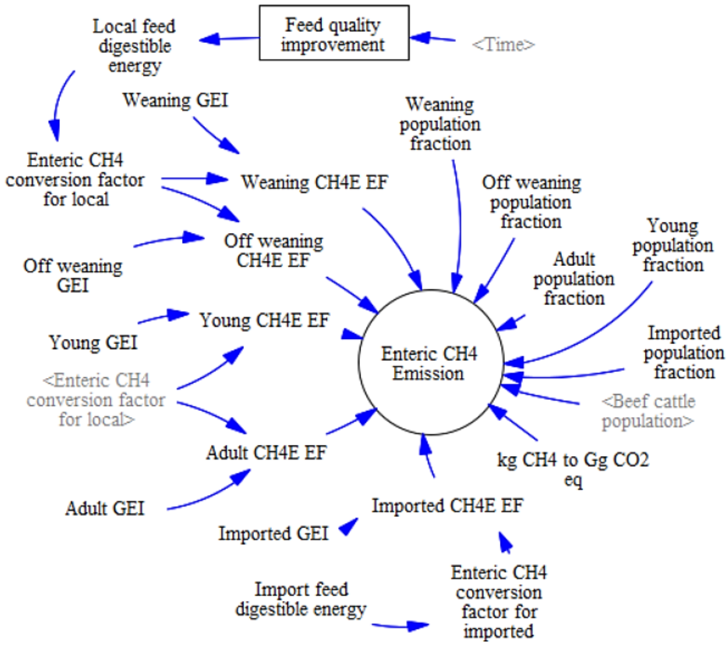

Figure 7. Feed Quality Improvement Scenario Effect on CH_4 Emission

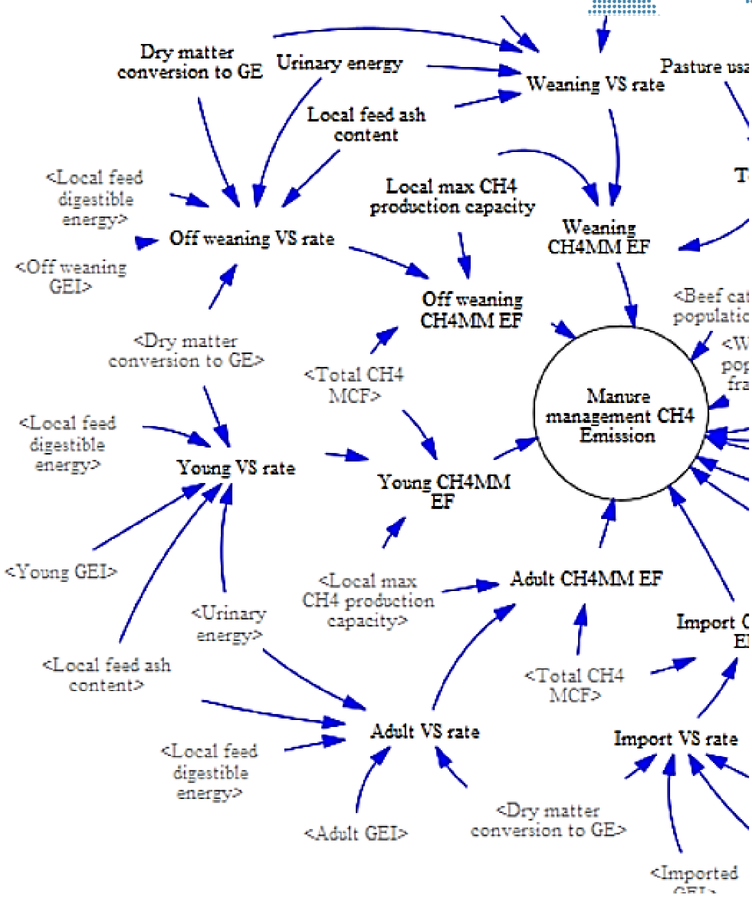

Figure 8. Feed Quality Improvement Effect on Manure Management CH_4 Emission

Table 3. Scenario Result

Emission	Scenario 1	Scenario 2	Scenario 3
Enteric CH4	-	15%	9%
Manure management CH4	28%	-	10.4%
Manure management N2O	0.09%	-	-
Overall Reduction	2%	4%	3%

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