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Master's Thesis

印度養牛產業之腸道發酵甲烷排放減量潛力與成本分析

Mitigation potential and costs of enteric methane emissions from Indian bovine sector

Student: 陳方婕

Advisor: 李慧琳

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Abstract

The purpose of this study is to find alternative rations to help the Indian cattle and buffalo sector reduce enteric methane emissions. We suggested a practical and low-cost method, in which the composition of rations used in 2010 was adjusted to attain emissions reductions. In this research, we analyzed enteric emissions and feed costs. We used the GLEAM-i model to calculate enteric emissions, which is based on the IPCC Tier 2 approach. The GHG calculations with the GLEAM-i model are detailed and comprehensive. Enteric emissions are associated with energy requirements. The energy requirements of cattle and buffalo are based on their live weight, gender, and function (to produce milk or meat or to provide labor). We identified 16 groups of bovines according to their different energy requirements. For each group, we imposed six scenarios of alternative rations that aimed to reduce enteric emissions. Among the six scenarios, the proportion of feed materials of higher digestibility is increased, thus replacing those of lower digestibility. Combining the mitigation potential and feed costs of the alternative rations, Scenario 6 presents the best choice, followed by Scenarios 5, 4, 3, 2, and then 1. Scenario 6 could attain a 1.5% reduction of enteric emissions (8.7 million t_{CO_2}-eq/year) and a 13% reduction in the feed costs ($3,828 USD/year) from the 2010 benchmark. In the short term, Scenario 6 would be the best choice for India to cut enteric emissions without adding significant financial burden. The relatively more costly Scenarios 1–5 could be feasible when India achieves better economic viability.

Keywords: cattle, buffalo, enteric emissions, feed costs, India, feed composition, GLEAM-i

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Abbreviations

AF	Adult females
AFZ	French Association for Animal Production
AM	Adult males
CH_4	Methane
CIRAD	French Agricultural Research Center for International Development
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
DM	Dry matter
DMI	Dry matter intake
EF	Emissions factor
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GLEAM	Global Livestock Environmental Assessment Model
GWP_{100}	Global warming potential with a time horizon of 100 years
INRA	French National Institute for Agricultural Research
IPCC	Intergovernmental Panel on Climate Change
kg CO_2-eq	Kilograms of CO_2 equivalent
kg DM	Kilograms of dry matter
kt CO_2-eq	Thousand tons of CO_2 equivalent
kt DM	Thousand tons of dry matter
LCA	Lifecycle assessment
LW	Live weight
Ym	Methane conversion factor
MF	Meat females or fattening females
MM	Meat males or fattening males
RF	Replacement females
RM	Replacement males
t CO_2-eq	Tons of CO_2 equivalent

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Definitions of commonly used terms

Adult females	Producing milk and calves
Adult males	Working and reproducing
Beef herd	Animals fed for meat production
CO_2-equivalent emissions	This is a standard for comparing different GHG emissions (IPCC). Over a given time horizon, the amount of GHG emissions is converted into CO_2 emissions.
Cohort	Animals divided into categories based on age, sex, and function (e.g. AF, AM, etc.).
Crop residues	Materials left in farmland after harvesting crops (e.g. bran, straw, and leaves).
Dairy herd	Animals fed for milk production and meat production.
Emissions factors	Factors that define the amount of GHG emissions (e.g. kg CH_4 per head per year).
Feed material	Category of individual feed (e.g. fodder beet, maize silage, etc.).
Global Warming Potential$_{100}$	Compared to the same amount of CO_2, the relative impact of GHG on climate change with a 100-year time horizon (IPCC).
Grassland-based systems	Systems for livestock production. More than 10% of DM is produced in farmland. The average stocking rate is less than 10 heads per hectare each year (Sere & Steinfeld, 1996).
Meat females	Meat females that are fattened for meat production

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	but not in feedlots
Meat females in feedlots	Meat females fattened for meat production in feedlots (only for cattle)
Meat males	Meat males fattened for meat production but not in feedlots
Meat males in feedlots	Meat males fattened for meat production in feedlots (only for cattle)
Mixed farming systems	Systems for livestock production. More than 10% of DM is from stubble and crop byproducts or the production value is not from livestock farming activities (Sere & Steinfeld, 1996).
Ration	The mixture of feed materials in animal diets.
Replacement females	Replacement females that replace culled and dead adult females
Replacement males	Replacement males that replace culled and dead adult males

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Executive summary (摘要)

反芻動物透過飼料的食用獲取熱量，但飼料在腸道發酵的過程中會產生甲烷。反芻類動物之腸道發酵(enteric fermentation)是全球農業部門溫室氣體(greenhouse gas, GHG)排放的最大來源。2017 年全球腸道甲烷排放量佔全球農業 GHG 排放量的 39% (約 21 億噸CO_2當量)(FAOSTAT, 2019)。糧食需求和人口的增加是畜牧業溫室氣體排放量成長的重要驅動力。

人口和經濟成長潛力將會使印度牛隻腸道甲烷排放量迅速增加。印度是全球腸道甲烷排放量最大的國家:2017 年的排放量為 2.9 億噸(CO_2當量)，佔全球腸道甲烷排放量的 14%(全球腸道甲烷排放量主要的國家請參見 Chapter 1 的 Table 1)。2018 年印度人口達到 13 億，佔全球人口的 18% (FAOSTAT, 2020)。聯合國預測印度 2030 年的人口將增加到 15 億人，成為全球人口密度最高的國家。同時，未來印度之經濟成長潛力將大幅躍進，而這將帶動其國內對肉類及乳製品的需求。因此，印度畜牧業之 GHG 減量將是未來該國及全球關注的重點。

農業是印度經濟中很重要的部門。2016 年農業部門的 GDP 佔印度 GDP 的 23% (約 5,090 億美元)，佔勞動力人口的 59% (約 255 百萬個工作)(WTTC, 2017)。2018 年印度的牛肉產量達 430 萬噸 (USDA, 2018)。此外，就 GHG 排放量而言，印度在 1990-2015 年期間的農業部門 GHG 排放量增加了 1.3 億噸(CO_2當量)且 2017 年印度農業部門之 GHG 排放量佔全球總 GHG 排放量的 12%(約 6.4 億噸CO_2當量) (FAOSTAT, 2019)。Table 2 列出 2016 年全球 GHG 主要排放國之牛肉生產的排放密集度(emissions intensity)-即:生產一公斤的牛肉所排放之溫室氣體。雖然印度的牛肉產量最低，但是牛肉的排放密集度最高。印度、巴西、中國和美國每公斤的牛肉分別會產生 82、36、19 和 12 公斤的溫室氣體 (FAOSTAT, 2019)。

改變動物飼料的配比是一種簡單可行且低成本的排放減量作法(O'Mara et al., 1998; Martin, Morgavi, & Doreau, 2009)。因此，本研究旨在分析 2010 年印度黃牛和水牛之口糧[1](ration)比例調整可達到的腸道甲烷排放減量及其成本。本文除了探討腸道發酵之甲烷減排量外，亦考量改變配比後的飼料成本，以反映

Table 2. Emissions intensity for beef from the top countries in 2016 (kg CO_2-eq/kg)

	Production (tons)	Emissions (tons)	Emissions intensity (kg CO_2-eq/kg)
India	2,522,301	205,858,301	82
Brazil	9,284,000	331,465,609	36
China	7,365,802	141,740,442	19
United States	11,470,489	139,004,659	12
World	69,799,812	1,887,834,000	27

Source: Collected and calculated from FAOSTAT

[1] 口糧是指牛每日需要攝取的乾物質(dry matter)數量，口糧以乾物質為計算基礎，計算牛隻的熱量攝取量。

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減量排放的經濟成本。我們採用全球畜牧業環境評估模型(GLEAM-i)進行評估。GLEAM-i 是由聯合國糧食及農業組織 (UN-FAO) 開發的模型，用於計算牲畜飼養的溫室氣體排放量[2]。

本研究挑選印度黃牛和水牛[3]腸道發酵之甲烷排放量進行計算。2017 年印度之腸道甲烷排放量佔其農業 GHG 排放量的 45%(FAOSTAT,2019)。印度之腸道甲烷排放量主要來自於黃牛和水牛。2017 年印度黃牛佔所有牲畜之腸道甲烷排放量 47%,其次是水牛(45%)、山羊(5%)、綿羊(2%)和其他動物(1%) (FAOSTAT,2019)。此外，由於本研究之目的在於調整 2010 年在養牛隻的口糧配比，口糧配比調整後的產肉(奶)量變動則不在本研究之研究範疇內，因此，我們的分析焦點在於每頭牛之腸道甲烷排放量，而非每公斤產品之腸道甲烷排放量。

GLEAM-i 使用 IPCC Tier2 方法計算腸道發酵之甲烷排放量。IPCC Tier2 的計算是相對 Tier 1 方法詳細，計算所需的參數資料相當多。腸道發酵之甲烷排放量與牛隻的能量需求(energy requirements)密切相關。牛隻的能量需求依其體重、性別、功能(以產奶、產肉或是提供獸力為主)等因素而有所不同，因此，GLEAM-i 將牛隻分成不同的農業系統和類別。農業系統類型包含草原放牧系統和混合農業系統，牛隻的類別包含成年動物和替代動物。印度成年牛隻和替代牛隻之 GHG 總排放量佔牛隻 GHG 總排放量的 98%(GLEAM-i)(詳情請參見 Chapter 5 的 Table 8)。由於粗飼料(roughage)佔牛隻之口糧總攝入量 75%以上(詳情請參見 Chapter 4 的 Table 7)，因此，本研究僅探討粗飼料。印度黃牛及水牛之口糧包含 12 種粗飼料:鮮草、乾草、甜菜根、穀物青貯飼料(grain silage)、玉米青貯飼料(maize silage)和其他作物殘茬[4](crop residues)。

Figure 2 列出腸道甲烷排放量計算之概況。由於每 55.56MJ 的能量損失(energy loss)[5]會轉換為一公斤的甲烷，因此，55.56 被定義為每公斤甲烷之熱量含量(energy content of methane)。為了取得能量損失，首先，要先計算牛隻攝取的熱量和甲烷轉化因子[6](methane conversion factor，Ym)。牛隻攝取的熱量是根據每日飼料總攝入量(feed intake)和口糧平均熱量(average gross energy content)計算而來的。口糧中每種飼料的攝入量是以百分比的方式表示佔乾物質總攝入量的比例。口糧中每種飼料之熱量和口糧成分會影響口糧平均熱量，而口糧平均熱量和牛隻的能量需求會影響飼料攝入量。飼料攝入量和牛隻的能量需求是根據 IPCC Tier 2 方法(2006)進行計算。本研究提到的牛隻之能量需

[2] GLEAM-i 根據 IPCC(2014)將腸道發酵之甲烷排放量轉換成二氧化碳當量，二氧化碳 100 年的全球暖化潛力值(Global warming potential, GWP_{100})是 1，甲烷 100 年的全球暖化潛力值是 34。換句話說，一單位的甲烷排放量造成暖化的潛力是一單位二氧化碳排放量的 34 倍。本研究所有的甲烷排放量皆以二氧化碳當量表示。

[3] 包含以產乳為主的奶牛(dairy herd)和以產肉為主的肉牛(beef herd)。

[4] 包含稻草、麩、葉子等。

[5] 指無法被牛隻吸收的熱量轉化為甲烷，以排氣的方式從牛的體內排出。

[6] 以百分比的方式表示能量損失。FAO 根據 IPCC 的定義設定 Ym 值以反映全球不同的飼料品質和餵養特徵 (Opio et al.,2013)。IPCC 定義 Ym 為 6.5±1% (Eggleston et al.,2006)，6.5 代表消化率為 65%時的能量損失。

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求包含淨能量需求(net energy requirements)和總能量需求[7](gross energy requirements)。由於本研究牛隻之體重、工作時數、產乳量、出生率等會影響淨能量需求的因素假設固定不變，因此，本研究牛隻之淨能量需求為固定。牛隻之總能量需求會因牛隻之淨能量需求和口糧平均消化率(average digestibility of ration)而變動。由於每種飼料之消化率皆不同(詳情請參見Chapter 4 的 Table 6)，因此，口糧配比會影響口糧平均消化率。攝取消化率較高之飼料會提高口糧平均消化率，亦代表牛隻所吸收的熱量較多。隨著口糧平均消化率的提高，甲烷轉化因子會降低。Ym 值越低代表能量損失越少，亦表示排放較少之腸道甲烷排放量。

[7] 就黃牛和水牛而言，總能量需求包含維持基礎代謝(maintenance)之熱量、牛隻活動(activity)所需之熱量、產奶之熱量(僅適用於奶牛及母牛)、工作之熱量(僅適用於公牛)、懷孕之熱量和牛隻成長所需之熱量(僅適用於替代動物)。

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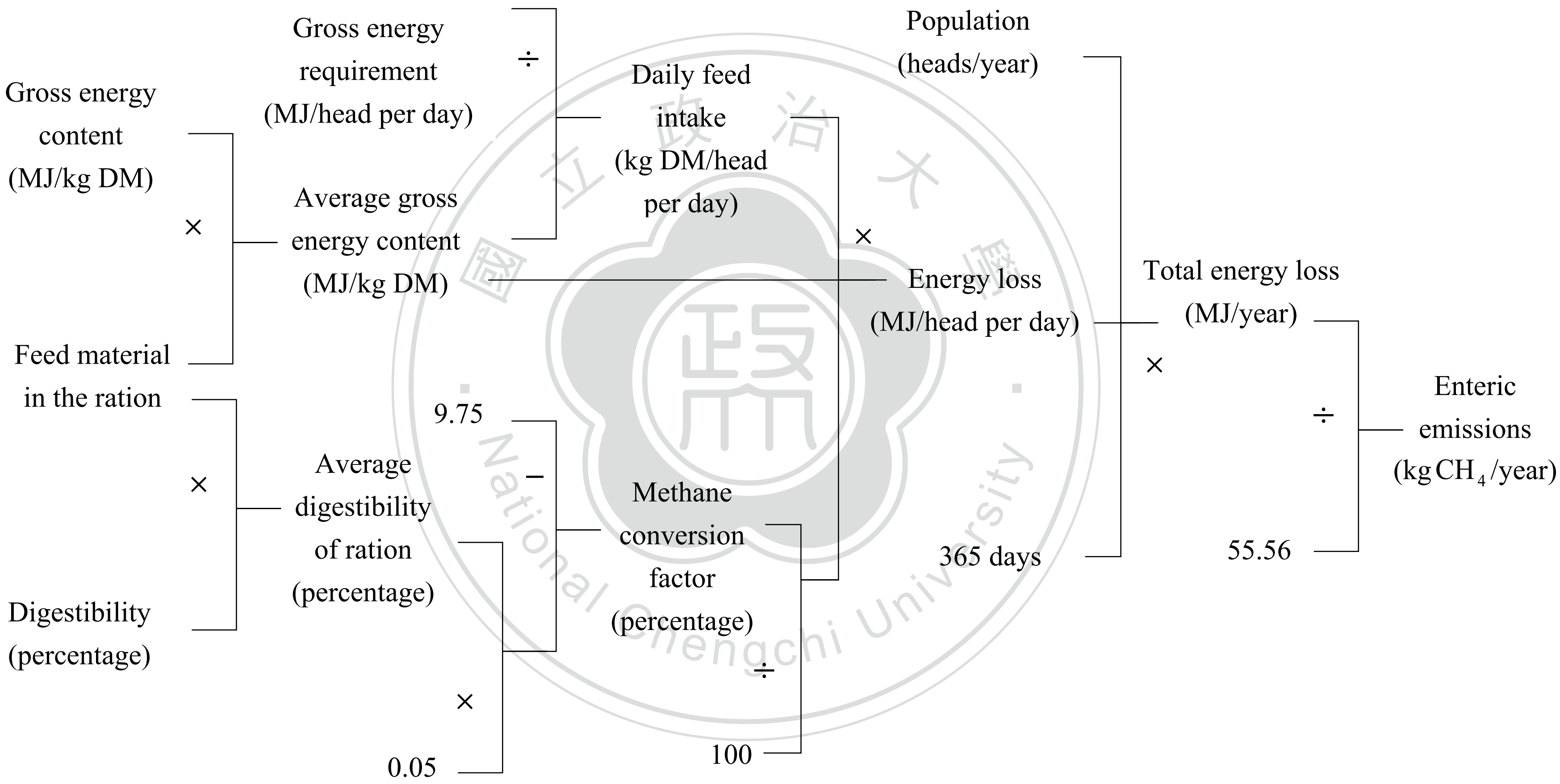

Figure 2: Overview of methane emissions calculations
Source: Organized from GLEAM-i

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本研究之研究設計以 12 種粗飼料為主，從中挑選兩種飼料為一組，每種飼料皆可與其餘 11 種飼料為一組，共有 132 種餵養方式。每組中以其中一種飼料取代另一種飼料的攝取量，前者取代其餘飼料之飼料稱為替代飼料(alternative feed material)，後者會被取代之飼料稱為被替代飼料(replaced feed material)。我們假設一次只改變兩種飼料的配比，其餘飼料之比例為固定。替代飼料取代之攝取量是根據原先 2010 年飼養牛隻方式之被代替飼料佔乾物質總攝取量的百分比，因此，新配比之口糧中不含有被替代飼料。Table 9 列出改變口糧配比之例子，假設口糧中僅含有三種飼料:飼料 A、B 和 C，分別佔 2010 年原先餵養牛隻方式之乾物質總攝入量的 10%、30%和 60%。假設以飼料 A 替代飼料 B，則口糧之新配比中的飼料 A、B 和 C 分別佔新餵養方式之乾物質總攝入量的 40%、0%和 60%。

此外，本研究假設 2010 年牛隻之各種飼料攝取量為新餵養方式的供給量上限。假設新餵養方式之其中一種飼料攝入量大於 2010 年原先餵養方式該飼料之攝入量，則將從其他國家進口該飼料至印度。我們假設鮮草與乾草之進口數量為無限且價格為零。由於作物殘茬之產量難以計算，因此，作物殘茬之進口量不在本研究之研究範疇內。重新調整 2010 年口糧之配比後，作物殘茬之攝取量皆為印度國產。假設不進口任何作物殘茬至印度，則會產生兩種限制。首先，無法以作物殘茬替代其他飼料；其次，2010 年新餵養方式之乾物質總攝入量必須小於原先餵養方式之乾物質總攝入量。

Table 10 說明 2010 年新餵養方式之乾物質總攝入量必須少於原先餵養方式

Table 9. Percentage of DMI in the ration

	Feed material A	Feed material B	Feed material C
In 2010	A0 = A/(A + B + C) = 10	B0 = B/(A + B + C) = 30	C0 = C/(A + B + C) = 60
Scenario	A1 = A/(A+C) = 10 + 30 = 40	B1 = B/(A + C) = 0	C1 = C/(A + C) = 60

Table 10. Total DMI per day in 2010 and the scenario

	Fresh grass	Maize silage	Any crop residues	Other feed materials	DIETDI	GEtot	DMI
Unit	Percentage of DMI				Percentage	MJ/ head	kg DM/ head
2010	4% (0.32 kg)	8% (0.65 kg)	49% (3.96 kg)	39% (3.15 kg)	61.2	0.141	8.08
Scenario	12% (0.98 kg)	0% (0 .00 kg)	49% (4.02 kg)	39% (3.20 kg)	60.9	0.143	8.20

Note: The data in parentheses indicate the actual DMI
Source: Collected and calculated from GLEAM-i

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之乾物質總攝入量的原因。改變口糧配比會影響口糧的平均消化率，在牛隻之淨能量需求為固定的情況下，口糧平均消化率變小代表牛隻較難攝取能量，牛隻需要攝取更多口糧平均消化率較小之飼料才能達到相同的淨能量需求。如果以原先的餵養方式飼養牛隻，每頭牛每日僅需攝取0.141 MJ的熱量及可達到淨能量需求，亦表示牛隻每日僅需攝取8.08公斤之乾物質。如果以新餵養方式飼養牛隻，口糧平均消化率僅為60.9%，每頭牛每日需攝取0.143 MJ的熱量才能達到淨能量需求，亦表示牛隻每日需攝取8.20公斤之乾物質。即使2010年原先餵養方式和新餵養方式之作物殘茬佔乾物質總攝入量的百分比為固定，牛隻於新餵養方式下實際攝取的作物殘茬之攝入量仍然大於2010年原先餵養方式所攝取之作物殘茬攝入量。本研究設計以減少腸道甲烷排放量為目標，因此，以腸道甲烷排放係數（公斤 CO_2 當量/公斤乾物質）小之飼料代替腸道甲烷排放係數相對較大之飼料。

Table 11 列出每種飼料腸道甲烷之排放係數及 132 種新餵養方式。根據我們的研究設計-不進口作物殘茬，因此，替代飼料不可為作物殘茬且改變口糧配比後的作物殘茬之乾物質攝入量不高於原先餵養方式的作物殘茬之乾物質攝入量，亦即排除有 P 或 DM 之新餵養方式。此外，不以腸道甲烷排放係數高之飼料代替腸道甲烷排放係數低之飼料，亦即排除有 E 之新餵養方式。根據我們的研究設計，可替代 2010 年原先餵養方式以減少腸道甲烷排放量的新餵養方式共有 37 種。

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Table 11. Emissions factor (kg CO_2 -eq/kg DM) of each feed material and feasible method

	EF	Fodder beet	Rice crop residues	Fresh grass	Grain silage	Maize silage	Hay	Maize crop residues	Sugarcane crop residues	Millet crop residues	Sorghum crop residues	Grain crop residues	Wheat crop residues
Fodder beet	0.56	-	1	2	3	4	5	6	7	8	9	10	11
Rice crop residues	0.7	P, E	-	P	P	P	P	P	P	P	P	P	P
Fresh grass	0.71	E	E	-	12	DM	13	14	15	16	17	18	19
Grain silage	0.73	E	E	E	-	DM	20	21	22	23	24	25	26
Maize silage	0.73	E	E	E	E	-	27	28	29	30	31	32	33
Hay	0.76	E	E	E	E	E	-	DM	DM	34	35	36	37
Maize crop residues	0.76	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P	P	P
Sugarcane crop residues	0.77	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P	P
Millet crop residues	0.78	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P
Sorghum crop residues	0.81	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P
Grain crop residues	0.84	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P
Wheat crop residues	0.85	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-

Note: E indicates that the emissions factor (kg CO_2 -eq/kg DM) of alternative feed materials is relatively higher. P indicates that the production of crop residues is uncertain. DM indicates that the dry matter intake is higher than in 2010.
Source: EF were calculated from GLEAM-i

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在這 37 種新餵養方式中，替代飼料共有五種:甜菜根、鮮草、穀物青貯飼料、玉米青貯飼料和乾草。被代替飼料有四到十一種。Table 13 列出 37 種餵養方式所產生之腸道甲烷排放量與飼料成本的百分比變化[8]，以放牧系統中黃牛的母奶牛為例子。第 1 種飼養方式至第 11 種飼養方式之替代飼料為甜菜根。第 12 種飼養方式至第 19 種飼養方式之替代飼料為鮮草。第 20 種飼養方式至第 26 種飼養方式之替代飼料為穀物青貯飼料。第 27 種飼養方式至第 33 種飼養方式之替代飼料為玉米青貯飼料。第 34 種飼養方式至第 37 種飼養方式之替代飼料為乾草。表格中每種替代飼料之新餵養方式以腸道甲烷排放量小至大排序。於這 37 種餵養方式中比較腸道甲烷排放量與飼料成本，我們將排除腸道甲烷排放量與飼料成本相對較高的餵養方式。

以放牧系統中黃牛的母奶牛為例子，2010 年原先飼養方式之每頭牛每年的腸道甲烷排放量為 2122 公斤(CO_2當量)，飼料成本為 2033(美元)（其他組別之腸道甲烷排放量與飼料成本之百分比變化請參見 Appendix A 的 Table A1 至 Table A15)。第 1 種餵養方式（以甜菜根代替水稻殘茬）可取代第 7 種餵養方式。第 1 種餵養方式可降低 11.7%的腸道甲烷排放量，但是第 7 種餵養方式僅能降低 10.6%的腸道甲烷排放量，且成本相對較高。無其他餵養方式可取代第 3 種餵養方式（以甜菜根代替穀物青貯飼料）。第 3 種餵養方式可減少 7.6%的腸道甲烷排放量，但成本增加 36.7%，雖然第 1、7、11 種餵養方式可減少更多的腸道甲烷排放量，但飼料成本相對較高。無其他餵養方式可取代第 11 種餵養方式（以甜菜根代替小麥殘茬）。第 11 種餵養方式可減少 10.2%的腸道甲烷排放量，但飼料成本增加 39.4%。雖然第 1、7 種餵養方式可減少更多的腸道甲烷排放量，但飼料成本相對較高。

第 12 種餵養方式（以新鮮草代替穀物青貯飼料）可取代第 14、16、20、21、34 與第 35 種餵養方式。第 12 種餵養方式可減少 1.5%的腸道甲烷排放量，同時降低 13.1%的飼料成本。第 14、16、20、21、34 和第 35 種餵養方式可減少之腸道甲烷排放量少於第 12 種餵養方式，且飼料成本相對較高。第 19 種餵養方式（以新鮮草代替小麥殘茬）可取代第 2,4,6,8,9,13-18,20-28,30-32 與第 34-37 種餵養方式。第 19 種餵養方式可減少 5.1%的腸道甲烷排放量，同時減少 3.5%的飼料成本。第 2,4,6,8,9,13-18,20-28,30-32,34-37 種餵養方式可減少之腸道甲烷排放量少於第 19 種餵養方式，且飼料成本相對較高。第 33 種餵養方式（以玉米青貯飼料代替小麥殘茬）可取代第 2,4-6,9,10 和第 29 種餵養方式。第 33 種餵養方式可減少 6.3%的腸道甲烷排放量，但增加 18.4%的飼料成本。第 2,4-6,9,10 與第 29 種餵養方式可減少之腸道甲烷排放量少於第 33 種餵養方式，且飼料成本相對較高。同時比較腸道甲烷排放量與飼料成本後，有 6 種可行且不會被取代的新飼養方式。

[8] 指改變口糧配比後，與 2010 年原先飼養方式之腸道甲烷排放量與飼料成本的差異。

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Table 13. Percentage change in methane emissions and feed costs in 2010 (AF of dairy cattle in grassland systems)

AF of dairy cattle in grassland systems										
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-11.7	44.7	Grain silage	26	Wheat crop residues	-3.9	8.0
	7	Sugarcane crop residues	-10.6	56.0		25	Grain crop residues	-2.4	4.6
	11	Wheat crop residues	-10.2	39.4		22	Sugarcane crop residues	-1.9	13.6
	3	Grain silage	-7.6	36.7		24	Sorghum crop residues	-1.3	4.1
	10	Grain crop residues	-6.3	23.7		20	Hay	-1.0	6.2
	5	Hay	-5.3	27.0		23	Millet crop residues	-0.8	3.0
	6	Maize crop residues	-4.5	26.8		21	Maize crop residues	-0.3	6.6
	9	Sorghum crop residues	-4.4	19.3	Maize silage	33	Wheat crop residues	-6.3	18.4
	4	Maize silage	-4.0	33.8		29	Sugarcane crop residues	-5.3	28
	8	Millet crop residues	-3.1	14		32	Grain crop residues	-3.9	10.9
	2	Fresh grass	-2.4	19.3		27	Hay	-2.6	13.2
Fresh grass	19	Wheat crop residues	-5.1	-3.5		31	Sorghum crop residues	-2.5	9.2
	15	Sugarcane crop residues	-3.6	-2.6		28	Maize crop residues	-1.9	13.5
	18	Grain crop residues	-3.2	-2.3		30	Millet crop residues	-1.7	6.6
	17	Sorghum crop residues	-1.9	-1.4	Hay	37	Wheat crop residues	-2.4	-1.5
	13	Hay	-1.8	-1.4		36	Grain crop residues	-1.6	-1.1
	12	Grain silage	-1.5	-13.1		35	Sorghum crop residues	-0.6	-0.4
	16	Millet crop residues	-1.3	-1.0		34	Millet crop residues	-0.3	-0.3
	14	Maize crop residues	-1.1	-0.8					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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同時比較腸道甲烷排放量和飼料成本後，有 6 種可行且不會被排除的飼養方式。Table 14 列出本研究 6 種新餵養方式之替代飼料與被替代飼料。在這 6 種餵養方式中，替代飼料之消化率相對較高，例如:甜菜根、玉米青貯飼料與鮮草，被替代飼料之消化率相對較低(詳情請參見 Chapter 4 的 Table 6)。

以放牧系統中黃牛的母奶牛為例子(其他組別請參見 Chapter 6)，Figure 3 列出 2010 年新餵養方式每頭牛之腸道甲烷排放量與飼料成本。我們以腸道甲烷排放量(公斤 CO_2 當量)、飼料成本（美元）及每單位減排成本（美元/公斤 CO_2 當量)這三方面來討論此六種新餵養方式。就減少腸道甲烷排放量而言，第 1 種餵養方式為最佳選擇。第 1 種餵養方式可減少 11.7%的腸道甲烷排放量，其次為第 2 種餵養方式（10.2%）、第 3 種餵養方式（7.6%）、第 4 種餵養方式（6.3%）、第 5 種餵養方式（5.1%）與第 6 種餵養方式（1.5%）。就飼料成本而言，第 1 種餵養方式的飼料成本增加了 44.7%，其次是第 2 種餵養方式（39.4%）、第 3 種餵養方式（36.7%）、第 4 種餵養方式（18.4%）。第 5 種餵養方式可減少 3.5%的飼料成本。第 6 種餵養方式可減少 13.1%的飼料成本。同時考慮腸道甲烷排放量與飼料成本後，第 6 種餵養方式為最佳選擇（0.8 美元/公斤 CO_2 當量），其次為第 5 種餵養方式（1.0）、第 4 種餵養方式（1.2）、第 3 種餵養方式（1.4）、第 2 種餵養方式（1.5）與第 1 種餵養方式（1.6）。

Table 15（a）列出六種新餵養方式之影響腸道甲烷排放量之因素。改變配

Table 14. Alternative feed materials and replaced feed materials of each scenario

	Alternative feed materials	Replaced feed materials
Scenario 1	Fodder beet	Rice crop residues
Scenario 2	Fodder beet	Wheat crop residues
Scenario 3	Fodder beet	Grain silage
Scenario 4	Maize silage	Wheat crop residues
Scenario 5	Fresh grass	Wheat crop residues
Scenario 6	Fresh grass	Grain silage

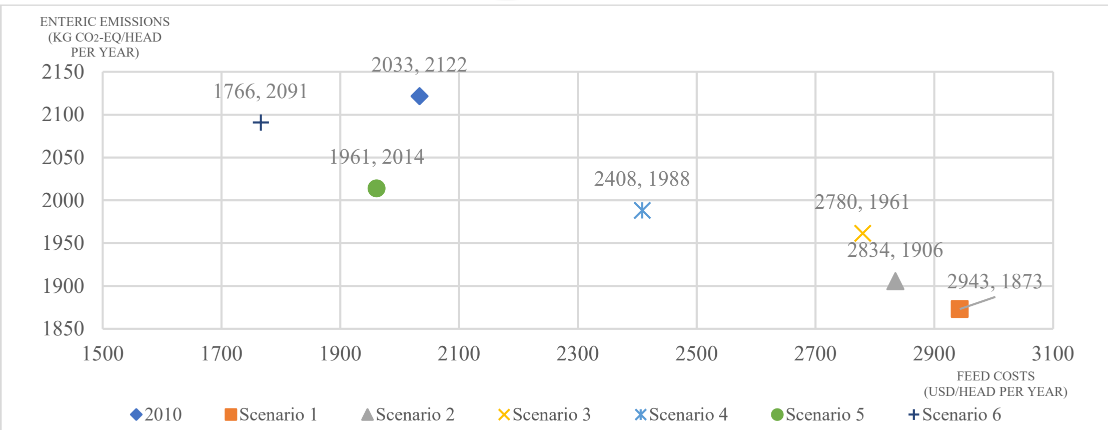

Figure 3: Enteric emissions and feed costs per head in 2010 for AF in grassland systems from dairy cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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比後的第 1 種餵養方式之口糧平均消化率是 65.2%，為六種餵養方式中口糧平均消化率最好之方法。其次為第 2 種餵養方式(64.7%)、第 3 種餵養方式(63.8%)、第 4 種餵養方式(63.3%)、第 5 種餵養方式(63.0%)與第 6 種餵養方式(61.9%)。口糧平均消化率較高可使牛隻較容易獲取能量，亦表示可減少腸道甲烷排放量。在淨能量需求相同的條件下，總能量需求隨著平均消化率的升高而降低。假設以第 1 種方式飼養牛隻，則每頭牛每年需攝取 47.1MJ 的熱量。第 2-6 種餵養方式之總能量需求分別為:47.7、48.7、49.2、49.7、51.2 MJ 的熱量。牛隻需多攝取平均消化率較低之口糧才能獲得相同的淨能量需求。在第 6 種餵養方式中，牛隻每日需攝入最多的乾物質(8.0 公斤乾物質)，其次為第 5 種方法（7.8)、第 4 種方法（7.7）第 3 種方法（7.7）第 2 種方法（7.5）及第 1 種方法（7.3)。乾物質之攝入量越高亦代表腸道甲烷排放量越高。

即使第 1 種餵養方式可減少最多的腸道甲烷排放量，但飼料成本也相對最高。飼料成本取決於飼料之價格與攝入量。由於本研究假設草及作物殘茬之價格為零，因此，飼料成本取決於甜菜根、玉米青貯飼料與穀物青貯飼料。為了計算飼料成本，需將乾物質攝入量轉換成以公斤為單位之飼料量。穀物青貯飼料之乾物質含量為 29.3%，其次為玉米青貯飼料(23.5%)及甜菜根(16.3%)。乾物質含量較低之飼料代表需購買更多的飼料以達到相同的乾物質攝取量。

Table 15（c）列出六種餵養方式之飼料成本，包含甜菜根、玉米青貯飼料與穀物青貯飼料。由於甜菜根之攝入量最大且每公斤之價格最高，因此，每種飼養方式之飼料成本以甜菜根為最高。由於每公斤穀物青貯飼料之價格較高，穀物青貯飼料之成本會高於玉米青貯飼料，第 4 種餵養方式除外。由於第 4 種餵養方式中，牛隻對玉米青貯飼料之需求高於 2010 年原先餵養方式之攝入量，因此印度於第 4 種餵養方式中需進口玉米青貯飼料以滿足牛隻之能量需求。由於玉米青貯飼料之進口價格高於印度國內穀物青貯飼料之價格，第 4 種餵養方式之玉米青貯飼料的成本高於穀物青貯飼料之成本。第 1 種餵養方式的總成本增加了 44.7%，其次為第 2 種餵養方式（39.4%)、第 3 種餵養方式（36.7%)、第 4 種餵養方式

Table 15(a). Emissions factors of scenarios for AF in grassland systems from dairy cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	-	61.2	51.7	8.1	2122
Scenario 1	10.6	65.2	47.1	7.3	1873
Scenario 2	8.8	64.7	47.7	7.5	1906
Scenario 3	9.9	63.8	48.7	7.7	1961
Scenario 4	8.8	63.3	49.2	7.7	1988
Scenario 5	8.8	63.0	49.2	7.8	2014
Scenario 6	9.9	61.9	51.2	8.0	2091

Source: Calculated and collected from GLEAM-i

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(18.4%)。第 5 種餵養方式可減少 3.5%的成本，而第 6 種餵養方式可減少 13.1%的成本。

於每種餵養方式中，各組別牛隻之腸道甲烷排放量差異來自於牛隻之淨能量需求。以第 1 種餵養方式為例 (詳情請參見 Chapter 6 的 Fig.19、Fig.20、Table 32(a)(b))。每頭成年母牛之腸道甲烷排放量（公斤 CO_2 當量/年）高於每頭成年公牛及替代動物之腸道甲烷排放量。成年母牛維持基礎代謝之淨能量需求係數較高（成年母牛：0.386；替代母牛：0.322；成年公牛和替代公牛：0.370)，意表示成年母牛需要更多的淨能量來維持基礎代謝。活動、懷孕所需之淨能量會隨著維持基礎代謝之淨能量而增加。由於維持基礎代謝、活動、懷孕與產奶所需之能量大於工作及成長所需之能量，因此，每頭成年母牛所需之能量高於每頭成年公牛。能量需求較高的牛隻需攝入較多的飼料，進而導致腸道甲烷排放量增加。由於 2010 年各組別牛隻之數量相異，因而造成有些組別之成年公牛及替代動物之腸道甲烷總排放量高於成年母牛之腸道甲烷總排放量(詳情請參見 Chapter 6 的 Table 32(a))。

對黃牛而言，大部分混合系統中每頭牛之腸道甲烷排放量高於草原放牧系統之腸道甲烷排放量，體重為造成不同農業系統間能量需求差異的主因(詳情請參見 Chapter 6 的 Table 31)。由於混合系統中黃牛之體重高於草原放牧系統中黃牛之體重，因此需攝取更多飼料已達到淨能量，例如:維持所需之能量、工作所需之能量及成長所需之能量。對水牛而言，混合系統中每頭牛之腸道甲烷排放量低於草原放牧系統，活動所需之淨能量為造成不同農業系統間能量需求差異的主因。於混合系統中，17%維持所需之淨能量用於活動所需之淨能量。於草原放牧系統中，36%維持所需之淨能量用於活動所需之淨能量。草原放牧系統中牛隻需要更多的體力去尋找食物或是移動。能量需求較高之黃牛與水牛會導致乾物質攝入量增加，亦表示腸道甲烷排放量會增加。由於 2010 年混合系統的牛隻數量遠大於草原放牧系統的牛隻數量，混合系統中牛隻之腸道甲烷總排放量高於草原放

Table 15(c). Feed costs in scenarios for AF in grassland systems from dairy cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	246	197	1591	2033
Scenario 1	222	178	2543	2943
Scenario 2	229	183	2422	2834
Scenario 3	0	187	2593	2780
Scenario 4	234	665	1510	2408
Scenario 5	237	190	1534	1961
Scenario 6	0	195	1572	1766

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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牧系統之腸道甲烷總排放量(詳情請參見 Chapter 6 的 Table 32(a))。

於大部分之組別，每頭奶牛之腸道甲烷排放量高於肉牛。由於肉牛不產奶，因此奶牛之淨能量需求高於肉牛之淨能量需求。於大部分之組別，2010 年奶牛之數量大於肉牛之數量，此為造成奶牛之腸道甲烷總排放量高於肉牛之腸道甲烷總排放量的主因(詳情請參見 Chapter 6 的 Table 32(a))。

於大部分之組別，黃牛產奶之淨能量需求小於水牛(黃牛：10.75 MJ/天；水牛：19.83 MJ/天)，因此每頭黃牛之腸道甲烷排放量少於水牛之腸道甲烷排放量。於大部分之組別，2010 年黃牛之數量大於水牛之數量，因而造成黃牛之腸道甲烷總排放量高於水牛腸道之甲烷總排放量(詳情請參見 Chapter 6 的 Table 32(a))。

根據本研究的結果發現印度牛隻之腸道甲烷排放量有減排的空間，短時間內可以第 6 種方式(以鮮草代替穀物青貯飼料)餵養印度所有牛隻，雖然僅減少 2%(約 875 萬噸 CO_2 當量/年)的腸道甲烷排放量，但可降低 13%的飼料成本(約 717 億美元/年)。此外，每單位之減排成本以第 6 種餵養方式為最低 (0.8 美元/公斤 CO_2 當量)。當印度經濟成長後，可以第 1-5 種餵養方式減少印度牛隻之腸道甲烷排放量，亦是以較貴之飼料成本去減少牛隻之腸道甲烷排放量。

2018 年印度人口達到 13 億，佔全球人口的 18%。聯合國預測印度 2030 年的人口將增加到 15 億人，成為全球人口密度最高之國家。同時，未來印度之經濟成長潛力將大幅躍進，而這將帶動其國內對肉類及乳製品之需求。人口和經濟成長潛力將會使印度牛隻腸道甲烷排放量迅速增加。因此，印度畜牧業之 GHG 減量將是未來該國及全球關注的重點。

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1. Introduction

Ruminants eat feed to get energy. However, some energy cannot be absorbed during enteric fermentation by ruminants and will be converted into methane. Enteric fermentation is the largest contributor of global GHG emissions from the agricultural sector. Global enteric emissions accounted for 39% (2.1 billion t CO_2 -eq) of agricultural emissions around the world in 2017 (FAOSTAT, 2019). Livestock GHG emissions will increase with food demand and population.

India was the world's largest emitter of enteric emissions in 2017; India emitted 290 million t CO_2 -eq of enteric emissions (14% of global enteric emissions) (FAOSTAT, 2019). In addition, emissions intensity (kg CO_2 -eq/kg) of beef in India was the highest (82), followed by Brazil (36), China (19), and the United States (12) (FAOSTAT, 2019). The growing potential of India's economy will increase domestic consumption of meat and dairy products. India's population was 1.3 billion in 2018, which accounted for 18% of the global population (FAOSTAT, 2020). The United Nations predicts that India's population will increase to 1.5 billion by 2030. India's growing population and economy will increase livestock emissions; this is expected to increase by 31% in 2010–2050 (Patra, 2014). Therefore, the mitigation of livestock emissions in India is an important global issue.

Dietary manipulation is a feasible and low-cost way to reduce enteric emissions (O'Mara et al., 1998; Martin, Morgavi, & Doreau, 2009). Therefore, the purpose of this research is to change the composition of rations[9] to help reduce enteric emissions from Indian cattle and buffalo[10]. In this research, we also analyzed feed costs. This study has two features: we analyzed enteric emissions and feed costs, which means that we

[9] Rations are the amount of DM that bovines must consume each day. Rations are in terms of DM to calculate energy requirements.
[10] Both cattle and buffalo include dairy and beef herds.

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combined environmental and economic aspects. In addition, we used GLEAM-i to calculate methane emissions[11], which is based on the IPCC Tier 2 approach (2006). We chose the GLEAM-i model because of its detailed categories of feed materials and calculation of methane emissions, which can achieve the goal of this research. Enteric emissions are associated with energy requirements. Energy requirements from bovines are based on their LW, gender, and function (to produce milk or meat or provide labor).

In our research design, we only analyzed 12 feed materials of roughage. Two feed materials of roughage were paired in a group. We only changed the percentage of DMI from feed materials in each group; the percentages of other feed materials are unchanged. We assume the feed consumption of feed materials in 2010 as the supply ceiling in our scenarios. If the feed intake in the scenario exceeded the 2010 levels, additional feed materials were assumed to be imported. We assumed that the imports of grass and hay were unlimited and free. We assume that crop residues were not imported to India because of uncertain import supplies. In other words, the feed intake from crop residues in the scenarios came from India; this assumption causes two limitations. Crop residues cannot replace any feed material and the total DMI in the scenario must be smaller than in 2010. We assume that the emissions factor (kg CO_2 -eq/kg DM) of alternative feed materials should be relatively smaller than replaced feed materials.

Chapter 2 introduces India's economy during 2007–2017, GHG emissions in India, and the process of producing methane emissions. Chapter 3 shows literature reviews, Chapter 4 introduces GLEAM-i and calculations of methane emissions, Chapter 5 introduces our research design, and Chapter 6 shows the results and scenarios of different cohorts, systems, herds, and bovines. We conclude this study in Chapter 7.

[11] Based on IPCC (2014), enteric emissions are converted into CO_2 -eq. The GWP_{100} of CO_2 is one and that of CH_4 is 34. In other words, the potential of global warming from one unit of CH_4 emissions is 34 times greater than one unit of CO_2 emissions.

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2. Background-GHG emissions by India

Growing populations, increasing incomes, and changes in food consumption are causing increases in beef demand (Steinfeld et al., 2006). The increasing demand for beef will increase livestock emissions (Steinfeld et al., 2006). Section 2.1 shows the top countries in terms of GHG emissions, agricultural GHG emissions, and enteric emissions around the world. Section 2.2 shows agricultural GHG emissions in India, Section 2.3 shows the economy, beef production, and population in India. Section 2.4 shows the process of producing methane emissions.

2.1 Top countries around the world in terms of GHG emissions

Table 1 shows the top countries in terms of enteric emissions, agricultural GHG emissions, and total GHG emissions in the latest year. In 2015, the total GHG emissions in India accounted for 6.8% of global GHG emissions (Oliver et al., 2016). In 2017, agricultural GHG emissions in India accounted for 11.8% of global GHG emissions from the agricultural sector (approximately 639 million tCO_2-eq). India emitted 290 million tCO_2-eq of enteric emissions in 2017, which accounted for 13.8% of global enteric emissions.

Table 1. Top countries in terms of enteric emissions, agricultural GHG emissions, and total GHG emissions for the previous year (million tCO_2-eq /year)

	Enteric emissions**	Agricultural GHG emissions**	Total GHG emissions*
India	290 (13.8)	639 (11.8)	2,455 (6.8)
Brazil	266 (12.7)	459 (8.5)	486 (1.3)
China	159 (7.6)	674 (12.5)	10,642 (29.5)
United States	126 (6.0)	355 (6.6)	5,172 (14.3)
World	2,100 (100)	5,410 (100)	36,062 (100)

Note: *Total GHG emissions for 2015. The total GHG emissions include CO_2, CH_4, N_2O, and F-gases (HFCs, PFCs, and SF_6). CO_2 from short-cycle biomass burning was not included. **Agricultural GHG emissions and enteric emissions were for 2017.
Sources: Total GHG emissions were collected from Oliver et al. (2016), agricultural GHG emissions, and enteric emissions were collected from FAOSTAT.

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Table 2 shows the top countries in terms of the emissions intensity of beef in 2016. Though beef production was the lowest in India, the emissions intensity of beef was the highest. The emissions intensity of beef in India, Brazil, China, and United States were 82, 36, 19, and 12 (kg CO_2 -eq/kg), respectively (FAOSTAT, 2019).

2.2 Agricultural GHG emissions in India

The GHG emissions total for India throughout 2010 was 2.7 billion t CO_2 -eq. The energy sector accounted for 51% of the total GHG emissions, followed by the agricultural sector (23%), "residential, commercial, institutional, and AFF[12]" (8%), transport (6%), industrial processes and product use (5%), waste (5%), other sources (1%), and land-use sources (1%) (FAOSTAT, 2019). Without removals from forestry, livestock emissions accounted for 65% of total GHG emissions from the Agriculture, Forestry, and Other Land Use (AFOLU) sector in 2013 (GHG Platform India, 2017). In addition, enteric emissions caused by cattle and buffalo were expected to increase by 7% and 13% in 2010–2025, respectively (Patra, 2014).

Table 3 shows the lifecycle emissions from livestock in 2010. Total GHG emissions include feed emissions, enteric emissions, emissions from manure management, and energy use. Enteric emissions from all livestock accounted for 62.8% of total GHG emissions from all livestock, followed by feed emissions (27.6%), manure

Table 2. Emissions intensity for beef from the top countries in 2016 (kg CO_2 -eq/kg)

	Production (tons)	Emissions (tons)	Emissions intensity (kg CO_2 -eq/kg)
India	2,522,301	205,858,301	82
Brazil	9,284,000	331,465,609	36
China	7,365,802	141,740,442	19
United States	11,470,489	139,004,659	12
World	69,799,812	1,887,834,000	27

Source: Collected and calculated from FAOSTAT

[12] AFF includes agriculture, forestry, and fishing.

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emissions (8.2%), and energy use (1.3%). Cattle and buffalo were the main contributors of enteric emissions (Patra, 2014). Enteric emissions from cattle and buffalo accounted for 35.4% and 24.2% of the total enteric emissions, respectively.

2.3 Economy, beef production, and population in India

Table 4 shows India's economic indicators for the past ten years. The growth rate of Gross Domestic Product (GDP) has been positive each year. In other words, the Indian economy has been increasing over the past ten years. The agriculture sector accounted for 23% of GDP (approximately 509 billion USD) and 59% of labor (approximately 255 million people) in 2016 (WTTC, 2017). During 2016–2017, livestock accounted for 26% of Gross Value Added (GVA) in the agriculture sector and 5% of total GVA in India (MoSPI, 2018). Both the per capita Gross National Income (GNI) and per capita Net National Income (NNI) have been gradually increasing over this time. The increasing income has driven Private Final Consumption Expenditure (PFCE). The expenditure on meat and meat products increased as incomes have increased in both rural and urban areas (Raghavendra, 2007). Beef consumption was positively correlated

Table 3. GHG emissions from different categories and livestock in 2010 (million t CO_2 -eq/year)

Category	Cattle	Buffalo	Sheep	Goat	Pig	Chicken	Livestock emissions
Feed emissions	139.1 (14.3)	98.1 (10.1)	4.8 (0.5)	9.0 (0.9)	2.0 (0.2)	15.3 (1.6)	268.3 (27.6)
Enteric fermentation	344.4 (35.4)	235.1 (24.2)	11.0 (1.1)	20.7 (2.1)	0.3 (0.0)	0.0 (0.0)	611.4 (62.8)
Manure management	42.4 (4.4)	28.8 (3.0)	0.9 (0.1)	1.8 (0.2)	3.0 (0.3)	3.2 (0.3)	80.1 (8.2)
Energy use	5.4 (0.6)	4.3 (0.4)	0.2 (0.0)	0.9 (0.1)	0.0 (0.0)	2.0 (0.2)	12.9 (1.3)
Total emissions	531.3 (54.6)	366.3 (37.7)	16.9 (1.7)	32.4 (3.3)	5.3 (0.5)	20.5 (2.1)	972.8 (100.0)

Note: Lifecycle emissions do not include post-farm emissions. The data in parentheses indicate the percentage of livestock emissions in India. Feed emissions include CO_2 from feed production, land use change from soy, palm kernel cake, and pasture expansion and N_2O from "fertilizer and crop residues", and "manure applied and deposited." Enteric emissions include methane emissions from enteric fermentation. Manure emissions include methane and nitrous oxide. GHG emissions from energy use include CO_2 from direct and indirect energy use.
Source: Collected from GLEAM-i

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with income in urban areas. Beef production in India is due to both domestic consumption and demand from other countries (USDA, 2016).

India produced about 4.3 million tons of meat in terms of carcass weight in 2018 (USDA, 2018). About 56% was domestic consumption and 44% was exported to other countries. Over the past ten years, the production of beef exported to Asia, the Middle East, and Africa has increased dramatically (USDA, 2016). About 97% of beef was exported to those regions (USDA, 2016). The top five beef export markets for 2013–2015 were Vietnam (795,000 tons), Malaysia (177,000 tons), Egypt (160,000 tons), Thailand (147,000 tons), and Saudi Arabia (99,000 tons) (USDA, 2016).

In addition, India's population has also increased over the past few years; Its annual population growth rate was 1.0–1.5% for 2007–2018 while the annual global population growth rate was 1.1–1.2% (FAOSTAT, 2020). In 2018, the Indian population accounted for 18% (1.3 billion) of the global population (7.6 billion). The Indian population is expected to reach 1.5 billion people by 2030 and become the world's most populous country (FAOSTAT, 2020). The demand for and production of beef will increase due to the increasing income and population.

Table 4. Per capita GDP, income, and expenditure at 2011–2012 prices in India (rupees)

	GDP	GNI	NNI	PFCE
2007–2008	60,466	60,217	54,649	34,318
2008–2009	61,468 (1.7)	61,111 (1.5)	55,101 (0.8)	35,349 (3.0)
2009–2010	65,394 (6.4)	65,011 (6.4)	58,442 (6.1)	36,610 (3.6)
2010–2011	69,994 (7.0)	69,240 (6.5)	62,170 (6.4)	38,543 (5.3)
2011–2012	71,609 (2.3)	70,908 (2.5)	63,462 (2.1)	40,250 (4.4)
2012–2013	74,599 (4.2)	73,722 (3.9)	65,538 (3.3)	41,936 (4.2)
2013–2014	78,348 (5.0)	77,370 (4.9)	68,572 (4.6)	44,423 (5.9)
2014–2015	83,091 (6.1)	82,107 (6.1)	72,805 (6.2)	46,667 (5.1)
2015–2016*	88,746 (6.8)	87,696 (6.8)	77,826 (6.9)	49,502 (6.1)
2016–2017**	93,888 (5.8)	92,775 (5.8)	82,229 (5.7)	52,443 (5.9)

Note: *Estimation of second revision. **Estimation of first revision. The data in parentheses indicate the change from the previous year (percentage).
Source: Collected from MoSPI (2018)

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2.4 Methane production

Bovine continuously chew and swallow feed from in and out of the first part of the animal's stomach, which is called rumen. There are many microbes in the rumen; these break down and ferment feed through three main stages as shown in Figure 1. First, large molecules of organic matter from feed are degraded into small molecules of organic matter. In this stage, carbohydrates are degraded into monosaccharides and proteins are degraded into amino acids in a process called hydrolysis. Then, small molecules of organic matter are converted into H_2, CO_2, and volatile fatty acids in a process called fermentation. The final stage is called methanogenesis. CO_2 and H_2 are synthesized by methanogens[13] through the last stage. Bovine excrete methane from their bodies through hiccupping and farting. A paper shows the details of methanogenesis (Morgavi et al., 2010).

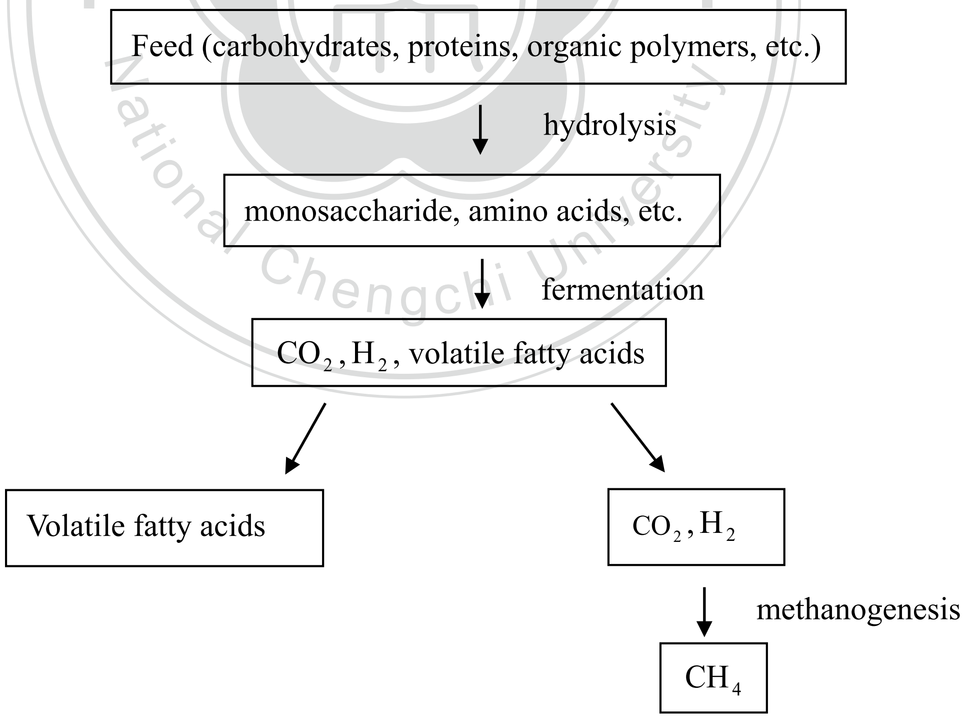

Figure 1: The three main stages of methane production
Source: Organized from Morgavi et al. (2010)

[13] Methanogens are microbes that produce methane.

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3. Literature reviews

Raghavendra (2007) studied meat consumption patterns, meat preferences, the economics of meat retail, and the problems faced in meat marketing in 2007. The research area is Hubli-Dharwad and includes 200 households, 20 bulk consumers, and 35 retailers. This study used Tabular analysis and Garrett's ranking technique. The former method was used to analyze households' characteristics, preferences for meat and meat products, consumption patterns, and problems in meat marketing. The latter was used to rank the main factors considered in meat consumption. The study indicated that 90% and 80% of households in urban areas and rural areas, respectively, were non-vegetarian. Per capita meat consumption and expenditures increased with income. Family tradition was the main factor that affected meat consumption, no matter what type of meat. When considering meat purchase decisions, nutritional value and taste were the two major factors.

Patra (2014) studied livestock emissions in India, developing countries, and the world during 1960–2010. The author also predicted emissions in 2025 and 2050. The data included enteric emissions, manure methane, and manure nitrous oxide. The author used the IPCC Tier 1 approach (2006) to calculate livestock emissions. Livestock emissions in India accounted for 14.1% of global livestock emissions, which were 2,771 million tCO_2-eq in 2010. Approximately 85.6% came from enteric emissions, followed by 10.3% from manure methane and 4.1% from manure nitrous oxide. For India, livestock emissions were 392 million tCO_2-eq in 2010. About 91.8% was from enteric emissions, followed by 7.0% from manure methane and 1.2% from manure nitrous oxide. The annual growth rates of all these three emissions sources in India for 1961–2010 were greater than throughout the rest of the world. The annual growth rate of livestock emissions in developing countries and developed countries were 1.2% and

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0.1%, respectively. In the year 2050, livestock emissions were expected to be 515, 2,930, and 3,528 million tCO_2-eq in India, developing countries, and the world, respectively. The expected increase in demand for meat and dairy products will cause livestock emissions to increase in developing countries.

GHG Platform India (2017) studied GHG emissions in Union Territories and every Indian state in 2005–2013. In this study, GHG includes CO_2, CH_4, and N_2O. Emissions sectors were divided into four categories: energy, industry, Agriculture, Forestry, and Other Land Use (AFOLU), and the waste sector. The estimates were based on IPCC (2006). The total emissions were 1,546 million tCO_2-eq in 2005 and reached to 2,417 million tCO_2-eq in 2010. During this period, the compounded annual growth rate for total emissions in India was 5.6%. The energy sector accounted for 63% of total emissions in 2013, followed by the industry sector (26%), AFOLU sector (7%), and waste sector (4%). The annual growth rate of GHG emissions from the energy, industry, and waste sectors were 3–9%. For the AFOLU sector, the compounded annual rate of GHG emissions was -1.9% because of the increase in removals from forestry and sluggish cattle populations. Per capita emissions were 1.4 tCO_2-eq in 2005 and increased to 1.93 tCO_2-eq in 2013.

USDA (2016) analyzed the production and export of beef in India. India accounted for 5% of exported beef around the world in 1999–2001, which had increased to 20% by 2013–2015. The rapid growth of Indian beef exports is predicted due to low costs, the large population of buffalo, and the development of export-oriented processors. India produced about 4.2 million tons of beef in 2015, of which they exported about 2 million tons to other countries. India exported about 97% of its beef to Asia, the Middle East, and Africa. Beef exports from India face tariff protection in certain countries. The continuing problem of controlling foot-and-mouth disease (FMD) may prevent beef from entering developed countries such as the United States, Canada, and Japan. The

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study indicated that India may deal with the increased demand for exports by rearing male calves and feeding animals.

Morgavi et al. (2010) studied the relationship between methanogenesis and microbes. Degradation of fibrous plant materials produces H_2 and methanogens mainly use H_2 and CO_2 to produce methane. Other microbes affect the quantity of microbiota or methaneogens. On the condition that the number of methanogens remains the same, the decrease in methane production is due to either the availability of H_2 or the change in rumen microbiota. The number of protozoa is highly correlated to methane emissions. Reducing the number of protozoa may present a way to reduce methane. Increasing the proportion of fibrolytic microorganisms[14] may also cause methane emissions to decrease. This method will not affect feed degradability.

O'Mara et al. (1998) studied the effect of feeding Holstein–Friesian cows maize silage instead of grass silage in terms of feed intake and milk production. They fed 56 Holstein–Friesian cows different diets over nine weeks; these diets included concentrates and mixtures of maize silage and grass silage. There were four kinds of feed mixture regarded as treatments. In terms of DM, the proportions of maize silage in the four treatments were 0%, 33%, 67%, and 100%. To provide similar crude protein concentration, the concentrates with crude protein were 180, 225, 285, and 340 g per kg of DM, respectively, for those four treatments. The Daily DMI of the four treatments were 8.8, 9.7, 10.4, and 10.7 kg, respectively. The daily milk production for the four treatments were 21.4, 23, 23.1, and 22.7 kg, respectively. The mixture with 67% of maize silage maximized the yield of protein and fat at 1.6 kg per day. The protein concentration was also maximized in this treatment at 31.6 g per kg.

[14] Fibrolytic microorganisms can produce non-H_2.

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4. GLEAM-i

Section 4.1 introduces GLEAM-i and Section 4.2 presents an overview and calculations of methane emissions. Section 4.3 shows what data was used from GLEAM-i, including population, feed materials, and their nutritional values.

4.1 Introduction

GLEAM-i was developed by UN-FAO and is used to calculate livestock's lifecycle GHG emissions[15]. Lifecycle GHG emissions include pre-farm emissions, on-farm emissions, and post-farm emissions. Pre-farm emissions include indirect energy use such as machinery, animal buildings, and equipment; on-farm emissions include direct energy use, feed emissions, enteric fermentation, and manure management; post-farm emissions include transportation, processing, and packaging.

GLEAM-i is based on six modules: herd module, feed ration and intake module, feed emissions module, animal emissions module, manure module, and allocation module. Enteric methane emissions are calculated in the animal emissions module. The calculation of enteric emissions with GLEAM-i is based on the IPCC Tier 2 approach (2006); the calculation is detailed and comprehensive. Enteric emissions are associated with energy requirements. Cattle and buffalo energy requirements are based on their live weight, gender, and function (to produce milk or meat or to provide labor).

4.2 Overview and calculations of methane emissions

This section includes seven parts. Part 1 shows overview of methane emissions calculations and the other parts show methane emissions equations (FAO, 2017).

4.2.1 Overview of methane emissions calculations

Figure 2 shows an overview of methane emissions calculations. Every 55.56 MJ of

[15] GHG emissions include CO_2, CH_4 and N_2O.

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energy loss[16] will be converted into one unit of methane, which is called the energy content of methane. Methane emissions are excreted from bovines via hiccupping or farting. To derive the energy loss, we need to calculate the energy intake by animals and the methane conversion factor (Ym)[17].

Energy intake depends on the average energy content of rations and feed intake. Feed material i in a ration refers to the percentage of the total DMI. The average energy content of the ration depends on the energy content of each feed material and the feed composition. The feed intake depends on the average energy content of the ration and the energy requirement. We mention the gross and net energy requirements in our research, where we assume that the factors that affect the net energy requirement such as the live weight of bovine, working hours, etc. remain unchanged; therefore, the net energy requirements are fixed in our research. For cattle and buffalo, the gross energy requirement includes maintenance, activity, milk production, work, pregnancy, and growth.

The gross energy requirement depends on the net energy requirement by animals and the energy availability from feed intake. The gross energy requirement changes according to the energy availability from feed intake. Energy availability from feed intake depends on the digestibility of each feed material in the bovine's rumen. The average digestibility of a ration depends on the digestibility of each feed material and the feed composition. Increasing the average digestibility of rations decreases the methane conversion factor. Ym is based on feed quality. When Ym is small, the energy loss is small. Less energy loss causes reduced enteric emissions.

[16] Energy loss refers to the amount of energy that the bovine cannot absorb and will instead convert into methane.

[17] Methane conversion factor (Ym) means the percentage of energy that bovines can't absorb. The definition of Ym is 6.5±1 percent (Eggleston et al., 2006). 6.5 of Ym means at a digestibility of 65%. FAO developed specific Ym values in order to reflect diet quality and feeding features in the world (Opio et al., 2013).

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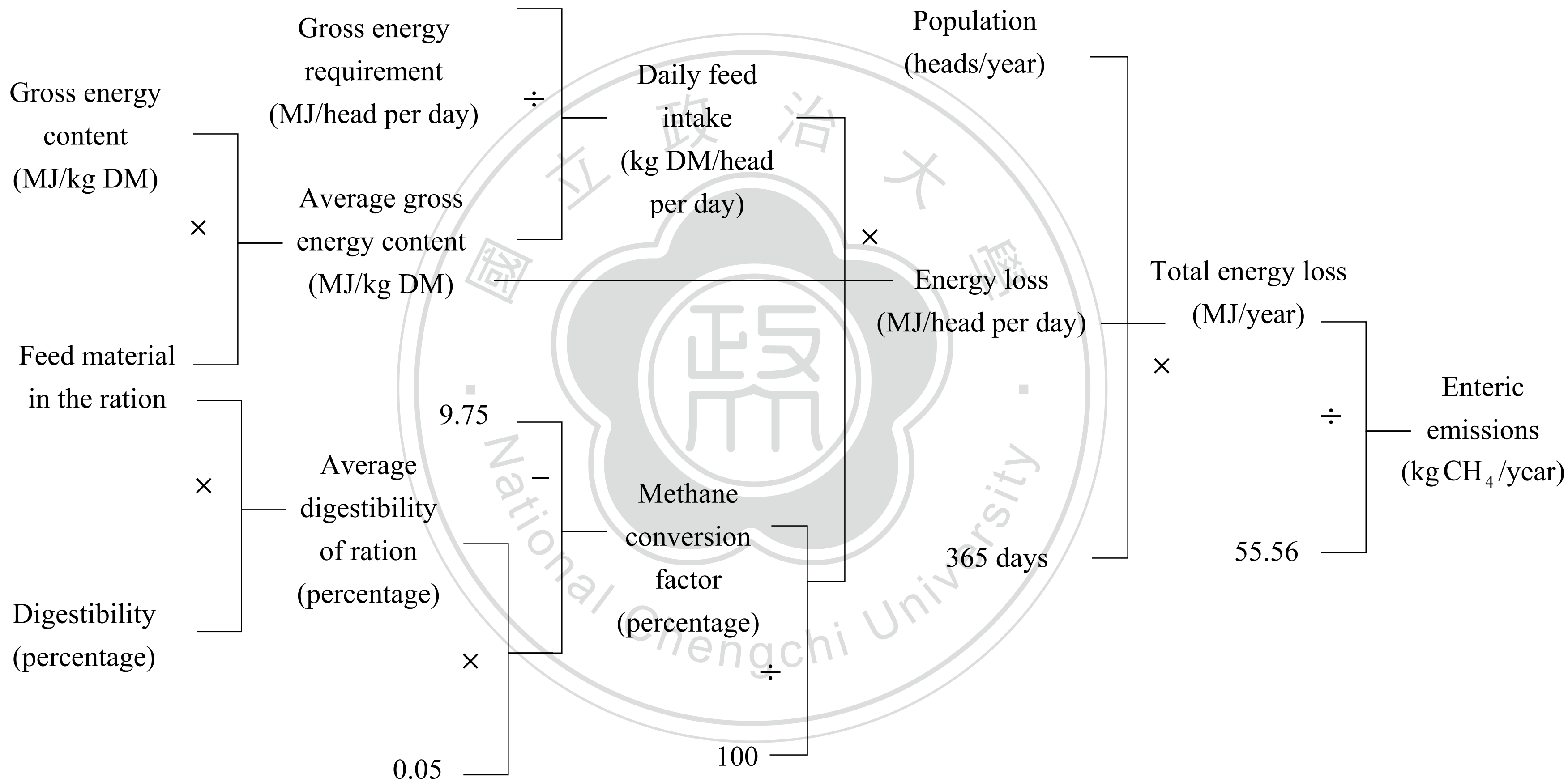

Figure 2: Overview of methane emissions calculations
Source: Organized from GLEAM-i

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4.2.2 Calculation of enteric emissions

Equation 1. shows the calculation of methane emissions. To get the total energy intake (MJ/head per day), the energy content of a ration is multiplied by daily DMI (kg DM/head). Then, the total energy intake per head is multiplied by the methane conversion factor to get the energy loss per head. Energy loss is multiplied by populations to get the total energy loss for the entire herd. To get the methane emissions for an entire herd per year, divide the total energy loss between the entire herd per year by the energy content of methane.

Equation 1

$$CH_4\text{-Enteric} = [DIETGE * DMI * (Ym/ 100)]*365*N / 55.65$$

where

CH_4-Enteric = methane emissions from enteric fermentation (kg CH_4/year).

DIETGE = average gross energy content of ration (MJ/kg DM). Equation 1.1

DMI = daily feed intake (kg DM/head per day). Equation 1.2

Ym = methane conversion factor (percentage). Equation 1.3

N = population of animals (heads/year).

55.65 = energy content of methane (MJ/kg CH_4).

4.2.3 Calculation of the average energy content of rations

The average energy content of rations depends on its composition. Equation 1.1 shows the calculation of the average energy content of rations. To get the average energy content of a ration, the energy content of each feed material is multiplied by its proportion in the ration. Table 6 shows the energy content of each feed material and Table 7 shows the percentage of roughage in the rations.

Equation 1.1

$$DIETGE = \Sigma i(FEEDi * GEi)$$

where

DIETGE = average gross energy content of ration (MJ/kg DM).

FEEDi = feed material i in the ration (fraction).

GEi = gross energy content of feed material i (MJ/kg DM).

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4.2.4 Calculation of daily feed intake

Equation 1.2 shows the calculation of daily DMI. DMI depends on the gross energy requirement of the animals and the average energy content of the ration. To get the daily feed intake, divide the animals' gross energy requirement by the average energy content of the rations.

Equation 1.2

$$DMI = GEtot / DIETGE$$

where

DMI = daily feed dry matter intake (kg DM/head per day).

GEtot = total gross energy requirement by animal (MJ/head per day).

DIETGE = average gross energy content of ration (MJ/kg DM). Equation 1.1

4.2.5 Calculation of gross energy requirement

The gross energy requirement is the sum of requirements for maintenance, activity, milk production, work, pregnancy, and growth. The energy requirement for maintenance increases with the live weight. Bovine in grassland systems need more energy for activities than in mixed systems. The large areas force them to walk for long distances to find feed. Bovine with more labor need more energy. The gross energy requirement changes with energy availability from feed intake, which depends on the digestibility of each feed material.

4.2.6 Calculation of the methane conversion factor (Ym)

Equation 1.3 shows the calculation of Ym. FAO developed specific Ym values to reflect diet quality and feeding features around the world (Opio et al., 2013) and Ym is based on feed quality. The conversion rate decreases as the ration's digestibility improves (Eggleston et al., 2006).

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Equation 1.3

$$Ym = 9.75 - 0.05 * DIETDI$$

where

Ym = methane conversion factor (percentage).

DIETDI = average digestibility of ration (percentage). Equation 1.3.1

4.2.7 Calculation of the average digestibility of rations

Ration digestibility represents the percentage of total energy intake that is metabolized. The average ration digestibility depends on its composition. Equation 1.3.1 shows the calculation of average digestibility of a ration. The digestibility of each feed material is multiplied by its proportion of the ration to get the average digestibility of rations. Table 6 shows the digestibility of each feed material.

Equation 1.3.1

$$DIETDI = \Sigma i(FEEDi * DIi)$$

DIETDI = average digestibility of ration (percentage).

FEEDi = feed material i in the ration (fraction).

DIi = digestibility of feed material i (percentage).

4.3 Data

This section only shows the data that is used from GLEAM-i in this research. This section has two parts; the first shows the herd size of cattle and buffalo in India in 2010, the second shows the percentage of feed materials in the ration and nutritional values of feed materials.

4.3.1 Herd size

Both cattle and buffalo include dairy herds and beef herds. There are two systems in each herd: grassland and mixed. Each group has six cohorts in India: AF, AM, RF, RM, MF and MM. The cohorts are different because of their different energy requirements. The unique feeding ways mean that these six cohorts are divided into four feeding groups. Group 1 just includes AF, Group 2 includes AM, RF, and RM, and Group 3

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includes MF and MM. Table 5 shows the herd size for cattle and buffalo in India.

4.3.2 Feed materials and nutritional values from roughage

According to the digestibility or energy content, dry matter yield per hectare and nitrogen content, there are 30 feed materials in GLEAM-i. Feed materials are divided into four categories: roughage, cereals, byproducts, and concentrate; only the roughage feed materials are discussed in this research. Table 6 shows the energy content and digestibility of roughage feed materials and Table 7 shows the daily DMI and percentage of feed materials from roughage among Indian cattle and buffalo in current situation in 2010.

Table 5(a). Herd size of cattle in India from 2010

	Dairy cattle		Beef cattle	
	Grassland	Mixed	Grassland	Mixed
AF	7,198,029	35,608,331	8,759,940	35,545,188
AM, RF, and RM	8,153,206	50,330,247	9,922,382	50,241,000
MF and MM	190,6073	146,991	1,185,116	1,965,843

Source: Collected from GLEAM-i

Table 5(b). Herd size of buffalo in India from 2010

	Dairy buffalo		Beef buffalo	
	Grassland	Mixed	Grassland	Mixed
AF	3,779,674	33,611,614	1,321,704	11,753,551
AM, RF, and RM	4,022,978	35,775,243	2,273,825	20,220,507
MF and MM	366,300	3,257,409	114,114	1,014,785

Source: Collected from GLEAM-i

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Table 6. Energy content and digestibility of feed materials for cattle and buffalo

Feed material	Energy content	Digestibility
Unit	kJ/kg DM	percentage
Fresh grass	18	66*
Hay or silage from grass	18	58*
Grain silage	18	59
Maize silage	19	69
Crop residues from rice	16	47
Crop residues from wheat	19	45
Crop residues from grain	18	44
Crop residues from maize	18	58
Crop residues from millet	18	50
Crop residues from sorghum	18	49
Crop residues from sugarcane	18	55
Fodder beet	17	85

Note: *Averaged value from continent specific figures
Source: Collected from GLEAM-i

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Table 7 (a). Percentage of each feed material in the ration for cattle with the current situation in India

	Dairy cattle				Beef cattle			
	Grassland		Mixed		Grassland		Mixed	
	AF	AM,RF, RM	AF	AM,RF, RM	AF	AM,RF, RM	AF	AM,RF, RM
Feed intake (kg DM/head per day)	8.1	4.5	7.8	5.9	6.3	4.5	6.7	5.9
Fresh grass	3.7	4.1	1.6	2.0	4.1	4.1	2.0	2.0
Hay or silage from grass	5.6	6.1	6.2	7.9	6.1	6.1	7.9	7.9
Silage from whole grain plants	9.9	10.8	8.3	10.5	10.8	10.8	10.5	10.5
Silage from whole maize plant	8.1	8.8	6.8	8.6	8.8	8.8	8.6	8.6
Crop residues from wheat	8.8	9.5	7.3	9.2	9.5	9.5	9.2	9.2
Crop residues from maize	5.4	5.9	4.5	5.7	5.9	5.9	5.7	5.7
Crop residues from millet	2.9	3.2	2.4	3.1	3.2	3.2	3.1	3.1
Crop residues from sorghum	4.1	4.4	3.4	4.3	4.4	4.4	4.3	4.3
Crop residues from rice	10.6	11.5	8.8	11.2	11.5	11.5	11.2	11.2
Crop residues from other grains	5.2	5.6	4.3	5.4	5.6	5.6	5.4	5.4
Crop residues from sugarcane	12.0	13.1	10.0	12.7	13.1	13.1	12.7	12.7
Fodder beet	13.7	15.0	11.4	14.5	15.0	15.0	14.5	14.5
Total roughage	90.0	98.0	75.0	95.0	98.0	98.0	95.0	95.0

Source: Collected from GLEAM-i

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Table 7 (b). Percentage of each feed material in the ration for buffalo with the current situation in India

	Dairy cattle				Beef cattle			
	Grassland		Mixed		Grassland		Mixed	
	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Feed intake (kg DM/head per day)	12.0	6.1	10.6	5.7	9.0	6.6	8.2	6.1
Fresh grass	3.5	3.9	1.6	2.0	3.9	3.9	3.8	2.0
Hay or silage from grass	5.3	5.9	6.2	7.9	5.9	5.9	5.7	7.9
Silage from whole grain plants	9.4	10.5	8.3	10.5	10.5	10.5	10.1	10.5
Silage from whole maize plant	7.7	8.6	6.8	8.6	8.6	8.6	8.3	8.6
Crop residues from wheat	8.3	9.2	7.3	9.2	9.2	9.2	8.9	9.2
Crop residues from maize	5.1	5.7	4.5	5.7	5.7	5.7	5.5	5.7
Crop residues from millet	2.8	3.1	2.4	3.1	3.1	3.1	3.0	3.1
Crop residues from sorghum	3.8	4.3	3.4	4.3	4.3	4.3	4.1	4.3
Crop residues from rice	10.0	11.2	8.8	11.2	11.2	11.2	10.8	11.2
Crop residues from other grains	4.9	5.4	4.3	5.4	5.4	5.4	5.3	5.4
Crop residues from sugarcane	11.3	12.7	10.0	12.7	12.7	12.7	12.3	12.7
Fodder beet	13.0	14.5	11.4	14.5	14.5	14.5	14.0	14.5
Total roughage	85.0	95.0	75.0	95.0	95.0	95.0	92.0	95.0

Source: Collected from GLEAM-i

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5. Research design

This chapter includes three sections; Section 5.1 shows the research scope, Section 5.2 shows data sources, and Section 5.3 shows our scenario design.

5.1 Research scope

In this research, we only analyzed enteric emissions. Agriculture emissions were 639 million tCO_2-eq in India in 2017. Enteric emissions accounted for 45% of agricultural emissions, synthetic fertilizers (17%), rice cultivation (15%), manure left on pasture (10%), manure management (5%), crop residues (4%), manure applied to soils (2%), burning from crop residues (1%), and others (1%) (FAOSTAT, 2019).

We only discussed cattle and buffalo in this research, including both dairy herds and beef herds. India emitted 290 million tCO_2-eq of enteric emissions in 2017, of which cattle accounted for 47% followed by buffalo (45%), goats (5%), sheep (2%), and others (1%) (FAOSTAT, 2019). The two systems are grassland-based and mixed farming.

According to Table 5, the population of adult animals and replacement animals accounted for at least 94% of the total population in both cattle and buffalo in 2010. Table 8 shows the enteric emissions caused by each cohort. AF, AM, RF, and RM accounted for at least 98% of enteric emissions in both cattle and buffalo (GLEAM-i).

We only discussed feed materials from roughage in this research. In India, there were only 12 feed materials considered roughage in the ration. Table 7 shows the proportion of feed materials from roughage. At least 75% of the total feed intake was from roughage.

5.2 Data

Data were collected from Feedipedia, GLEAM-i, and FAOSTAT. Feedipedia (https://www.feedipedia.org/) is a project by INRA, CIRAD, AFZ, and FAO. FAOSTAT

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is a database of global agricultural statistics compiled by the FAO.

The DM content of each feed material was collected from Feedipedia (https://www.feedipedia.org/). The DM content of grass is based on Bermuda grass. India is considered one of the places Bermuda grass originated and it is the main grass in tropical and subtropical regions. It is suitable for ruminants in the form of pastures and hay. The DM content of grain silage is based on wheat and the production of wheat in 2010 was much higher than other grain plants. The DM content of maize silage, which is <20%, was selected from Feedipedia. The DM content of millet crop residues was based on finger millet, which is the main small millet in India and is used to feed infant calves and growing animals in India (Seetharam, Riley, & Harinarayana, 1986).

The DM content of crop residues from grains is based on barley and includes bran, straw, and leaves. The crop residues from wheat and maize are based on bran and the crop residues from millet, sorghum, rice, and barley are based on straw. The crop residues from sugarcane are based on leaves. Herd size, gross energy content, total DMI and methane emissions were collected from GLEAM-i and the gross energy requirement from animals is calculated from GLEAM-i. The prices for each feed material were collected from FAOSTAT. The domestic price was reported as the

Table 8 (a). Enteric emissions caused by cattle (million t CO_2 -eq/year)

	Dairy cattle		Beef cattle	
	Grassland	Mixed	Grassland	Mixed
AF	15,272	71,811	14,720	63,455
	(61.0)	(47.9)	(54.5)	(44.6)
AM, RF, and RM	9,713	78,179	11,820	78,040
	(38.8)	(52.1)	(43.8)	(54.8)
MF and MM	52	44	450	805
	(0.2)	(0.0)	(1.7)	(0.6)
Total	25,037	150,034	26,991	142,300
	(100.0)	(100.0)	(100.0)	(100.0)

Note: The data in parentheses indicate the percentage of total enteric emissions from cattle
Source: Collected from GLEAM-i

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producer price in 2008 and the import price is reported as CIF[18]. The import price is the average price from all imported countries in 2010. There was no production of fodder beet in India in 2008–2012; therefore, the price of sugar beet is based on the 2012 import price.

5.3 Scenario design

In our scenario design, two feed materials of roughage were paired in a group. In a group, one feed material replaced the other. The former one was called an alternative feed material and the latter was called the replaced feed material. The percentage change is based on the percentage of DMI from the replaced feed material. After changing the percentage of feed material, the ration did not contain replaced feed material. The percentages of other feed materials were unchanged. Table 9 shows an

Table 8 (b). Enteric emissions caused by buffalo (million t CO_2 -eq/year)

	Dairy buffalo		Beef buffalo	
	Grassland	Mixed	Grassland	Mixed
AF	12,043	92,998	3,183	25,865
	(63.9)	(62.2)	(43.9)	(43.5)
AM, RF, and RM	6,561	54,679	3,994	33,005
	(34.8)	(36.6)	(55.1)	(55.5)
MF and MM	236	1,863	74	580
	(1.3)	(1.2)	(1.0)	(1.0)
Total	18,840	149,540	7250	59,450
	(100.0)	(100.0)	(100.0)	(100.0)

Note: The data in parentheses indicate the percentage of total enteric emissions from buffalo
Source: Collected from GLEAM-i

Table 9. Percentage of DMI in the ration

	Feed material A	Feed material B	Feed material C
In 2010	A0 = A/(A + B + C) = 10	B0 = B/(A + B + C) = 30	C0 = C/(A + B + C) = 60
Scenario	A1 = A/(A+C) = 10 + 30 = 40	B1 = B/(A + C) = 0	C1 = C/(A + C) = 60

[18] CIF includes costs, insurance and freight.

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example of changing the feed composition. If there were only three feed materials (feed materials A, B, and C) in the ration, we would use feed material A to replace feed material B as the new feed. The percentage of DMI in feed materials A, B, and C are 10%, 30%, and 60%, respectively, in the current situation. After changing the composition of the ration, the new percentage of DMI in feed materials A, B, and C were 40%, 0%, and 60%.

We assume the consumption of feed materials in 2010 as the supply ceiling in our scenarios. If the feed intake in our scenario exceeds the 2010 level, the additional feed materials are assumed to be imported. We assume that the imports of grass and hay are unlimited and free of charge. The import supplies of any crop residues are uncertain as they depend on the amount of crop residues that remain after the harvest. Therefore, we assume any crop residues are not imported to India. The assumption causes two limitations. First, crop residues cannot replace any feed material. Second, total the DMI in the scenario must be less than that in 2010.

Table 10 shows the reason why the DMI cannot be higher than in 2010. Changing the percentage of feed materials will affect the average digestibility of the ration. If the average digestibility of a ration is smaller, it means that the cattle and buffalo will struggle to meet their energy requirements. In this scenario, the average digestibility of the rations is only 60.9%. If the cattle and buffalo were fed with the new percentage of ration in this scenario, they would need 0.143 MJ per head each day. In this scenario, the gross energy requirement is higher because of the worse average digestibility of the ration. Under the condition that net energy requirements of the bovines are fixed, they will need to eat more feed to meet the same net energy requirement. In this scenario, cattle and buffalo need to eat 8.2 kg of DM per day to maintain their net energy requirements. Although the percentage of DMI from any crop residues remain the same between 2010 and the scenario, the actual DM fed to cattle and buffalo were higher in

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the scenario. This means that the crop residues need to be imported to India but we assume that crop residues are not imported.

In our research design, the emissions factor (kg CO_2 -eq/kg DM) of alternative feed materials should be relatively smaller than the replaced feed materials. Table 11 shows the emissions factors for each feed material and 132 methods. The emissions factors are calculated from GLEAM-i. Assume that each cohort of cattle and buffalo only eat one feed material in their ration. We can get the emissions factors for each feed material by dividing the total methane emissions by the total DMI. According to our research design, there are 37 feasible methods. Both P and DM are infeasible because they would require importing crop residues into India. E is infeasible because it would cause higher enteric emissions than the situation in 2010. The numbers refer 37 feasible and new feeding methods.

Table 10. Total DMI per day in 2010 and the scenario

	Fresh grass	Maize silage	Any crop residues	Other feed materials	DIETDI	GEtot	DMI
Unit	Percentage of DMI				Percentage	MJ/ head	kg DM/ head
2010	4% (0.32 kg)	8% (0.65 kg)	49% (3.96 kg)	39% (3.15 kg)	61.2	0.141	8.08
Scenario	12% (0.98 kg)	0% (0.00 kg)	49% (4.02 kg)	39% (3.20 kg)	60.9	0.143	8.20

Note: The data in parentheses indicate the actual DMI
Source: Collected and calculated from GLEAM-i

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Table 11. Emissions factor (kg CO_2 -eq/kg DM) of each feed material and feasible method

	EF	Fodder beet	Rice crop residues	Fresh grass	Grain silage	Maize silage	Hay	Maize crop residues	Sugarcane crop residues	Millet crop residues	Sorghum crop residues	Grain crop residues	Wheat crop residues
Fodder beet	0.56	-	1	2	3	4	5	6	7	8	9	10	11
Rice crop residues	0.7	P, E	-	P	P	P	P	P	P	P	P	P	P
Fresh grass	0.71	E	E	-	12	DM	13	14	15	16	17	18	19
Grain silage	0.73	E	E	E	-	DM	20	21	22	23	24	25	26
Maize silage	0.73	E	E	E	E	-	27	28	29	30	31	32	33
Hay	0.76	E	E	E	E	E	-	DM	DM	34	35	36	37
Maize crop residues	0.76	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P	P	P
Sugarcane crop residues	0.77	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P	P
Millet crop residues	0.78	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P	P
Sorghum crop residues	0.81	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P	P
Grain crop residues	0.84	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-	P
Wheat crop residues	0.85	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	P, E	-

Note: E indicates that the emissions factor (kg CO_2 -eq/kg DM) of alternative feed materials is relatively higher. P indicates that the production of crop residues is uncertain. DM indicates that the dry matter intake is higher than in 2010.
Source: EF were calculated from GLEAM-i

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To calculate feed costs, feed materials in terms of kg dry matter must be converted into kg. The feed intake of each feed material in terms of dry matter is estimated from GLEAM-i. Equations 2–4 shows the calculation of feed intake and feed costs. First, feed intake in terms of kg dry matter from each feed material is calculated using the current data from GLEAM-i. Then, the feed intake in terms of kg dry matter from each feed material is divided by dry matter content to get the feed intake in terms of kilograms. Finally, the feed intake in terms of kilograms is multiplied by the price to get the total feed costs.

Equation 2.

$$DMI * FEEDi = DMIi$$

where

DMI = daily feed intake (kg DM/head per day)

FEEDi = ration of feed material i in the ration (fraction)

DMIi = daily feed intake of feed material i (kg DM/head per day)

Equation 3.

$$DMIi/(DMi/100) = KGIi$$

where

DMIi = daily feed intake of feed material i (kg DM/head per day)

DMi = dry matter content of feed material i (percentage)

KGIi = daily feed intake of feed material i (kg/head per day)

Equation 4.

$$KGIi * Pi * 365 = C$$

where

KGIi = daily feed intake of feed material i (kg/head per day)

Pi = price of feed material i (USD/kg)

C = costs of total feed intake (USD/year)

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6. Result analysis

We discuss the enteric emissions and feed costs of six scenarios from different groups in the four sections of this chapter. First, we introduce how we chose six scenarios from 37 feasible feeding methods. Section 6.1 shows six scenarios for dairy cattle, Section 6.2 shows six scenarios for beef cattle, Section 6.3 shows six scenarios for dairy buffalo, and Section 6.4 shows six scenarios for beef buffalo. Section 6.5 shows the difference between cohorts, systems, herds, and bovines.

There are 37 feasible and new feeding ways, called results. Based on our research design, the replaced feed materials can be 4–11 feed materials. The alternative feed material for results 1–11 is fodder beet, the alternative feed material for results 12–19 is fresh grass, the alternative feed material for results 20–26 is grain silage, the alternative feed material for results 27–33 is maize silage, and the alternative feed material for results 34–37 is hay. For each alternative feed material, results are ranked from lower enteric emissions to higher enteric emissions. When comparing methane emissions and feed costs for these 37 feasible results, we will exclude all relatively poor results.

Table 12 shows methane emissions and feed costs per head for different groups of cattle and buffalo in the current situation in 2010. There are 37 feasible results in each cohort. Tables A1–A15 in Appendix A show the percentage change of methane emissions and feed costs for each result in different cohorts and systems. The percentage change indicates the difference after changing the feed composition from the current situation in 2010.

Set a cohort as an example. For AF dairy cattle in grassland systems, methane emissions per head was 2,122 (kg CO_2-eq/head per year) in the current situation of 2010. The feed costs per head was \$2,033 (USD/head per year) in the current situation

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of 2010. Table 13 shows the percentage change of methane emissions and feed costs for AF dairy cattle in grassland systems. Result 1 (fodder beet replacing rice crop residues) can replace Result 7. Result 1 can reduce methane emissions by 11.7% but Result 7 can only reduce methane emissions by 10.6% at higher costs.

No results can replace Result 3 (fodder beet replacing grain silage), which can reduce methane emissions by 7.6% but increases feed costs by 36.7%. Though Results 1, 7, and 11 can reduce methane emissions more than Result 3, the feed costs are relatively higher. Other results reduce methane emissions less than Result 3 with lower feed costs. No results can replace Result 11 (fodder beet replacing wheat crop residues), which can reduce methane emissions by 10.2% but increases feed costs by 39.4%. Though Results 1 and 7 can reduce methane emissions more than Result 11, their associated feed costs are relatively higher. Other results reduce methane emissions less than Result 11 with lower feed costs.

Result 12 (fresh grass replacing grain silage) can replace Results 14, 16, 20, 21, 34, and 35. Result 12 can reduce methane emissions by 1.5% while reducing feed costs by 13.1%. Results 14, 16, 20, 21, 34, and 35 all reduce methane emissions to less than Result 12 but their feed costs are relatively higher. Result 19 (fresh grass replacing wheat crop residues) can replace Results 2, 4, 6, 8, 9, 13–18, 20–28, 30–32, and 34–37 as it can reduce methane emissions by 5.1% while reducing feed costs by 3.5%. Results 2, 4, 6, 8, 9, 13–18, 20–28, 30–32, and 34–37 reduce methane emissions further than Result 19 but have relatively higher feed costs.

Result 33 (maize silage replacing wheat crop residues) can replace results 2, 4–6, 9, 10, and 29. Result 33 can reduce methane emissions by 6.3% but increases feed costs by 18.4%. Results 2, 4–6, 9, 10, and 29 all reduce methane emissions further than result 33 but have relatively higher feed costs. After comparing enteric emissions and feed costs, six scenarios are considered feasible and irreplaceable.

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Table 12. Enteric emissions and feed costs per head of cattle and buffalo in current situation in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Enteric emissions	kg CO_2-eq/ head per year	2,122	1,191	2,017	1,553	1,680	1,191	1,785	1,553
Feed costs	USD/ head per year	2,033	1,225	1,643	1,555	1,728	1,225	1,787	1,555

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Enteric emissions	kg CO_2-eq/ head per year	3,186	1,631	2,767	1,528	2,408	1,756	2,201	1,632
Feed costs	USD/ head per year	2,861	1,626	2,215	1,521	2,400	1,751	2,190	1,625

Source: Collected and calculated from GLEAM and FAOSTAT

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Table 13. Percentage change in methane emissions and feed costs in 2010 (AF of dairy cattle in grassland systems)

AF of dairy cattle in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-11.7	44.7	Grain silage	26	Wheat crop residues	-3.9	8.0
	7	Sugarcane crop residues	-10.6	56.0		25	Grain crop residues	-2.4	4.6
	11	Wheat crop residues	-10.2	39.4		22	Sugarcane crop residues	-1.9	13.6
	3	Grain silage	-7.6	36.7		24	Sorghum crop residues	-1.3	4.1
	10	Grain crop residues	-6.3	23.7		20	Hay	-1.0	6.2
	5	Hay	-5.3	27.0		23	Millet crop residues	-0.8	3.0
	6	Maize crop residues	-4.5	26.8		21	Maize crop residues	-0.3	6.6
	9	Sorghum crop residues	-4.4	19.3	Maize silage	33	Wheat crop residues	-6.3	18.4
	4	Maize silage	-4.0	33.8		29	Sugarcane crop residues	-5.3	28.0
	8	Millet crop residues	-3.1	14.0		32	Grain crop residues	-3.9	10.9
	2	Fresh grass	-2.4	19.3		27	Hay	-2.6	13.2
Fresh grass	19	Wheat crop residues	-5.1	-3.5		31	Sorghum crop residues	-2.5	9.2
	15	Sugarcane crop residues	-3.6	-2.6		28	Maize crop residues	-1.9	13.5
	18	Grain crop residues	-3.2	-2.3		30	Millet crop residues	-1.7	6.6
	17	Sorghum crop residues	-1.9	-1.4	Hay	37	Wheat crop residues	-2.4	-1.5
	13	Hay	-1.8	-1.4		36	Grain crop residues	-1.6	-1.1
	12	Grain silage	-1.5	-13.1		35	Sorghum crop residues	-0.6	-0.4
	16	Millet crop residues	-1.3	-1.0		34	Millet crop residues	-0.3	-0.3
	14	Maize crop residues	-1.1	-0.8					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table 14 shows alternative feed materials and replaced feed materials in each scenario. Among these six scenarios, there is a common feature among the alternative feed materials. The digestibility of alternative feed materials is better than the replaced feed materials such as fodder beet, maize silage, and fresh grass.

6.1 Dairy Cattle

Section 6.1 shows the enteric emissions and feed costs of six scenarios from different groups. We analyzed these six scenarios in terms of enteric emissions (kg CO_2-eq), feed costs (USD), and costs per unit of mitigating emissions (USD/kg CO_2-eq). Part 1 shows AF in grassland systems, Part 2 shows AM, RF, and RM in grassland systems, Part 3 shows AF in mixed systems, and Part 4 shows AM, RF, and RM in mixed systems.

6.1.1 AF in grassland-based systems

Table 15(a) shows the emissions factors of different scenarios. The ration with higher average digestibility is the main reason for the reduction in enteric emissions. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 65.2%, followed by Scenarios 2 (64.7%), 3 (63.8%), 4 (63.3%), 5 (63.0%), and 6 (61.9%). If the average digestibility of a ration is better, cattle will find it relatively easier to meet their energy requirements.

Under the condition of the same net energy requirement, the gross energy requirement decreases with the higher average digestibility. If cattle were fed with

Table 14. Alternative feed materials and replaced feed materials of each scenario

	Alternative feed materials	Replaced feed materials
Scenario 1	Fodder beet	Rice crop residues
Scenario 2	Fodder beet	Wheat crop residues
Scenario 3	Fodder beet	Grain silage
Scenario 4	Maize silage	Wheat crop residues
Scenario 5	Fresh grass	Wheat crop residues
Scenario 6	Fresh grass	Grain silage

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Scenario 6, they would need the highest energy requirement per year (51.2 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (49.7 MJ/year), followed by Scenarios 4 (49.2), 3 (48.7), 2 (47.7), and 1 (47.1). Cattle would need to eat more ration of lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (8.0 kg DM), followed by Scenarios 5 (7.8 kg), 4 (7.7), 3 (7.7), 2 (7.5), and 1 (7.3). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. No matter how much of other feed materials the cattle would eat, feed costs depend on fodder beet, maize silage, and grain silage. We assume the other feed materials were free. To calculate feed costs, feed materials in terms of kg dry matter must be converted into kg. The dry matter content of grain silage is the highest (29.3%), followed by maize silage (23.5%), and fodder beet (16.3%).

Table 15(b) shows feed intake in terms of DM and kg in Scenarios 1–6. Under the condition of the same DMI from each feed material, feed intake in terms of kg was higher with lower DM content. No matter how high the DMI of feed materials is in

Table 15(a). Emissions factors of scenarios for AF in grassland systems from dairy cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	-	61.2	51.7	8.1	2122
Scenario 1	10.6	65.2	47.1	7.3	1873
Scenario 2	8.8	64.7	47.7	7.5	1906
Scenario 3	9.9	63.8	48.7	7.7	1961
Scenario 4	8.8	63.3	49.2	7.7	1988
Scenario 5	8.8	63.0	49.2	7.8	2014
Scenario 6	9.9	61.9	51.2	8.0	2091

Source: Calculated and collected from GLEAM-i

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Scenarios 1–6, feed intake in terms of kg from fodder beet would be highest, followed by maize silage, and then grain silage.

Table 15(c) shows feed costs in Scenarios 1–6. The feed costs of fodder beet would be the highest for all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would make the

Table 15(b). Feed intake in scenarios for AF in grassland systems from dairy cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	991 (292)	1020 (240)	2485 (405)
Scenario 1	895 (264)	922 (217)	3973 (648)
Scenario 2	922 (272)	949 (223)	3785 (617)
Scenario 3	0 (0)	966 (227)	4052 (660)
Scenario 4	941 (278)	2012 (473)	2360 (385)
Scenario 5	956 (282)	984 (231)	2397 (391)
Scenario 6	0 (0)	1008 (237)	2456 (400)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content was collected from Feedipedia

Table 15(c). Feed costs in scenarios for AF in grassland systems from dairy cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	246	197	1591	2033
Scenario 1	222	178	2543	2943
Scenario 2	229	183	2422	2834
Scenario 3	0	187	2593	2780
Scenario 4	234	665	1510	2408
Scenario 5	237	190	1534	1961
Scenario 6	0	195	1572	1766

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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costs of maize silage higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would be increased by 44.7%, followed by Scenarios 2 (39.4%), 3 (36.7%), and 4 (18.4%). Scenario 5 would reduce feed costs by 3.5% and Scenario 6 would reduce feed costs by 13.1%.

Figure 3 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it can reduce enteric emissions by 11.7%, followed by Scenarios 2 (10.2%), 3 (7.6%), 4 (6.3%), 5 (5.1%), and 6 (1.5%). In terms of feed costs, these would increase by 44.7% in Scenario 1, followed by Scenarios 2 (39.4%), 3(36.7%), and 4 (18.4%). Scenario 5 would reduce feed costs by 3.5% and Scenario 6 would reduce feed costs by 13.1%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 would be the best choice (0.8 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.2), 3 (1.4), 2 (1.5), and 1 (1.6).

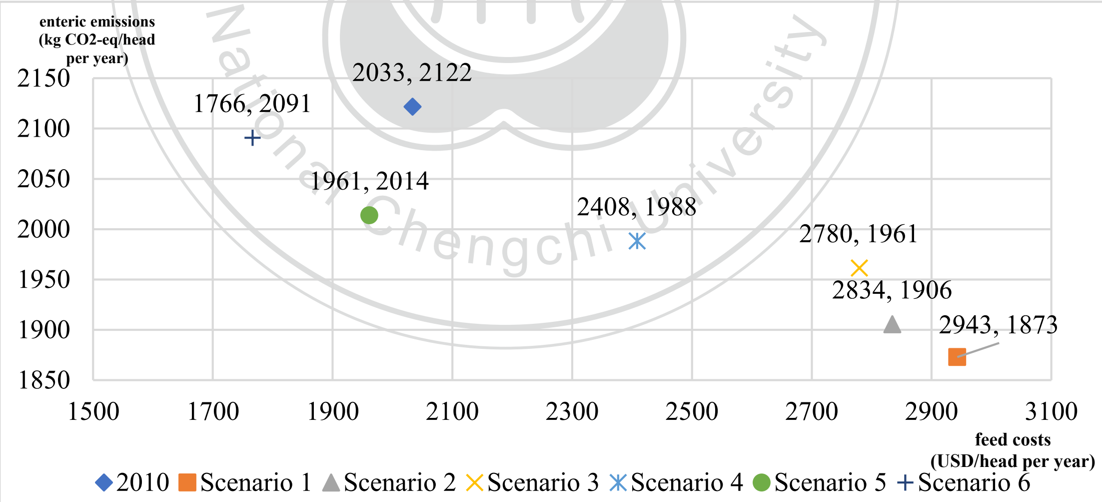

Figure 3: Enteric emissions and feed costs per head in 2010 for AF in grassland systems from dairy cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.1.2 AM, RF, and RM in grassland-based systems

Table 16(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 63.9%, followed by Scenarios 2 (63.4%), 3 (62.3%), 4 (61.8%), 5 (61.5%), and 6 (60.3%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (28.3 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (27.3 MJ/year), followed by Scenarios 4 (26.9), 3 (26.6), 2 (25.9,) and 1 (25.5). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (4.4 kg DM), followed by Scenarios 5 (4.3 kg), 4 (4.2), 3 (4.2), 2 (4.1), and 1 (3.9). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 16(b) shows the feed intake in terms of DM and kg in Scenarios 1–6. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and then grain silage.

Table 16(a). Emissions factors of scenarios for AM, RF, and RM in grassland systems from dairy cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.5	59.5	28.7	4.5	1191
Scenario 1	9.5	63.9	25.5	3.9	1023
Scenario 2	10.8	63.4	25.9	4.1	1045
Scenario 3	9.5	62.3	26.6	4.2	1082
Scenario 4	9.5	61.8	26.9	4.2	1100
Scenario 5	10.8	61.5	27.3	4.3	1117
Scenario 6	11.5	60.3	28.3	4.4	1170

Source: Calculated and collected from GLEAM-i

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Table 16(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would increase the costs of maize silage above that of grain silage in Scenario 4. In Scenario 1, the total

Table 16(b). Feed intake in scenarios for AM, RF, and RM in grassland systems from dairy cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	597 (176)	615 (144)	1498 (244)
Scenario 1	526 (155)	541 (127)	2333 (380)
Scenario 2	544 (160)	560 (132)	2233 (364)
Scenario 3	0 (0)	573 (135)	2403 (392)
Scenario 4	559 (165)	1195 (281)	1402 (229)
Scenario 5	570 (168)	586 (138)	1429 (233)
Scenario 6	0 (0)	605 (142)	1475 (240)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 16(c). Feed costs in scenarios for AM, RF, and RM in grassland systems from dairy cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	148	119	958	1225
Scenario 1	131	105	1493	1728
Scenario 2	135	108	1429	1672
Scenario 3	0	111	1538	1648
Scenario 4	139	393	897	1429
Scenario 5	141	113	914	1169
Scenario 6	0	117	944	1061

Note: The data in parentheses are the imported prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while imported prices are reported as CIF, which includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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feed costs would increase by 41.0%, followed by Scenarios 2 (36.5%), 3 (34.5%), and 4 (16.6%). Scenario 5 would reduce feed costs by 4.6% and Scenario 6 would reduce feed costs by 13.4%.

Figure 4 shows enteric emissions and costs per head in 2010. In terms of the mitigation potential, Scenario 1 presents the best choice. Scenario 1 could reduce enteric emissions by 14.1%, followed by Scenarios 2 (12.3%), 3 (9.2%), 4 (7.7%), 5 (5.1%), and 6 (1.5%). In terms of feed costs, these would increase by 41% in Scenario 1, followed by Scenarios 2 (36.5%), 3 (34.5%), and 4 (16.6%). Scenario 5 would reduce feed costs by 4.6% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.7).

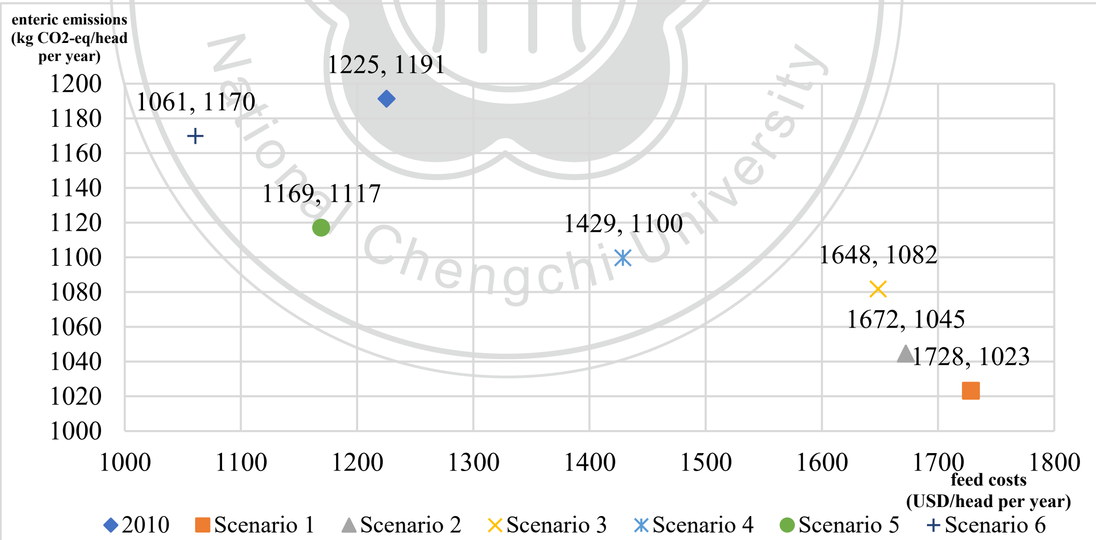

Figure 4: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in grassland systems from dairy cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.1.3 AF in mixed farming systems

Table 17(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 68.0%, followed by Scenarios 2 (67.5%), 3 (66.8%), 4 (66.4%), 5 (66.1%), and 6 (65.2%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (50.0 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (49.0 MJ/year), followed by Scenarios 4 (48.6), 3 (48.2), 2 (47.4), and 1 (47.0). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (7.8 kg DM), followed by Scenarios 5 (7.6 kg), 4 (7.5), 3 (7.5), 2 (7.4), and 1 (7.2). The ration with lower average digestibility and higher DMI cause higher enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 17(b) shows feed intake in Scenarios 1–6. No matter how high the DMI of feed materials is in different scenarios, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 17(c) shows the feed costs in Scenarios 1–6. The costs of fodder beet would

Table 17(a). Emissions factors of scenarios for AF in mixed systems from dairy cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	8.8	64.6	50.5	7.8	2017
Scenario 1	7.3	68.0	47.0	7.2	1828
Scenario 2	8.3	67.5	47.4	7.4	1854
Scenario 3	7.3	66.8	48.2	7.5	1896
Scenario 4	7.3	66.4	48.6	7.5	1917
Scenario 5	8.3	66.1	49.0	7.6	1936
Scenario 6	8.8	65.2	50.0	7.8	1994

Source: Calculated and collected from GLEAM-i

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be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be why the costs of maize silage is higher than grain silage in Scenario 4. In scenario 1, the feed total costs would be increased by 48.2%, followed by Scenarios 2 (41.9%), 3 (38.5%), and 4 (20.1%). Scenario 5 would reduce feed costs by 2.7% and Scenario 6 would reduce feed costs by 12.9%.

Table 17(b). Feed intake in scenarios for AF in mixed systems from dairy cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	800 (236)	824 (194)	2007 (327)
Scenario 1	740 (218)	762 (179)	3285 (535)
Scenario 2	758 (224)	780 (183)	3112 (507)
Scenario 3	0 (0)	791 (186)	3317 (541)
Scenario 4	769 (227)	1645 (387)	1930 (315)
Scenario 5	779 (230)	802 (188)	1954 (318)
Scenario 6	0 (0)	816 (192)	1989 (324)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 17(c). Feed costs in scenarios for AF in mixed systems from dairy cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	199	159	1285	1643
Scenario 1	184	147	2103	2433
Scenario 2	188	151	1992	2330
Scenario 3	0	153	2123	2275
Scenario 4	191	546	1235	1972
Scenario 5	193	155	1250	1599
Scenario 6	0	158	1273	1431

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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Figure 5 shows enteric emissions and costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it would reduce enteric emissions by 9.3%, followed by Scenarios 2 (8.1%), 3 (6.0%), 4 (5.0%), 5 (4.0%), and 6 (1.1%). In terms of feed costs, costs would increase the most in Scenario 1 (48.2%), followed by Scenarios 2 (41.9%), 3 (38.5%), and 4 (20.1%). Scenario 5 would reduce feed costs by 2.7% and Scenario 6 would reduce feed costs by 12.9%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.7 USD/kg CO_2 -eq) followed by Scenarios 5 (0.8), 4 (1.0), 3 (1.2), 2 (1.3) and 1 (1.3).

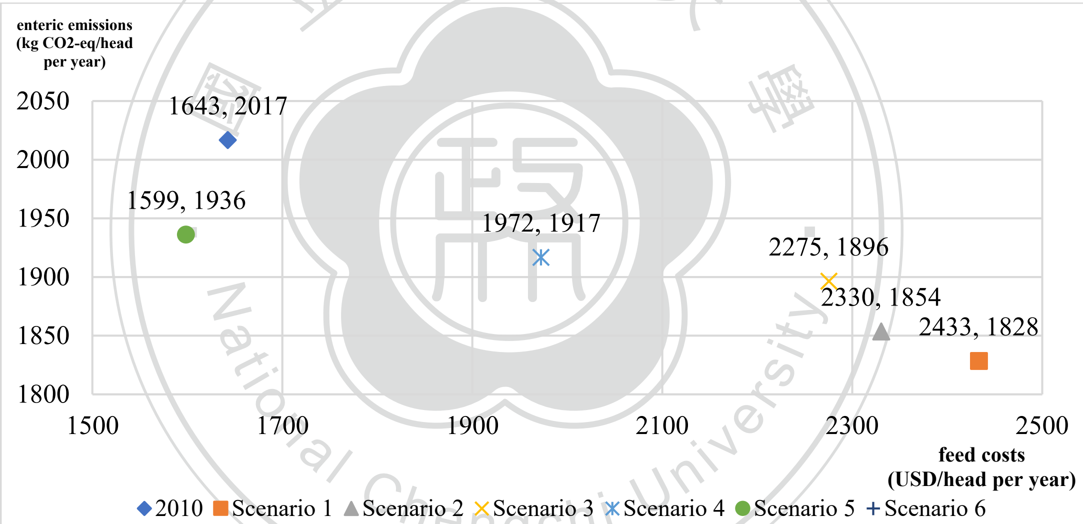

Figure 5: Enteric emissions and feed costs per head in 2010 for AF in mixed systems from dairy cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.1.4 AM, RF, and RM in mixed farming systems

Table 18 (a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.2%, followed by Scenarios 2 (63.7%), 3 (62.7%), 4 (62.2%), 5 (61.9%), and 6 (60.7%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (37.0 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (35.7 MJ/year), followed by Scenarios 4 (35.3), 3 (34.9), 2 (34.0), and 1 (33.5). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (5.8 kg DM), followed by Scenarios 5 (5.6 kg), 4 (5.5), 3 (5.5), 2 (5.4), and 1 (5.2). The ration with lower average digestibility and higher DMI cause higher enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 18(b) shows feed intake in Scenarios 1–6. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beets would be the highest, followed by maize silage and grain silage.

Table 18(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 18(a). Emissions factors of scenarios for AM, RF, and RM in mixed systems from dairy cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2 -eq/year
2010	11.2	60.0	37.5	5.9	1553
Scenario 1	9.2	64.2	33.5	5.2	1342
Scenario 2	10.5	63.7	34.0	5.4	1369
Scenario 3	9.2	62.7	34.9	5.5	1416
Scenario 4	9.2	62.2	35.3	5.5	1438
Scenario 5	10.5	61.9	35.7	5.6	1460
Scenario 6	11.2	60.7	37.0	5.8	1526

Source: Calculated and collected from GLEAM-i

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the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, total costs would increase by 41.8%, followed by Scenarios 2 (37.0%), 3 (34.9%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and Scenario 6

Table 18(b). Feed intake in scenarios for AM, RF, and RM in mixed systems from dairy cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (%)	29.3	23.5	16.3
2010	758 (224)	780 (183)	1900 (310)
Scenario 1	671 (198)	690 (162)	2976 (485)
Scenario 2	693 (204)	713 (168)	2845 (464)
Scenario 3	0 (0)	729 (171)	3058 (499)
Scenario 4	711 (210)	1521 (357)	1784 (291)
Scenario 5	724 (214)	746 (175)	1817 (296)
Scenario 6	0 (0)	769 (181)	1873 (305)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content was collected from Feedipedia

Table 18(c). Feed costs in scenarios for AM, RF, and RM in mixed systems from dairy cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	188	151	1216	1555
Scenario 1	166	133	1905	2204
Scenario 2	172	138	1821	2131
Scenario 3	0	141	1957	2098
Scenario 4	177	500	1142	1819
Scenario 5	180	144	1163	1487
Scenario 6	0	148	1199	1347

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

would reduce feed costs by 13.4%.

Figure 6 shows enteric emissions and feed costs per head for 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 13.6%, followed by Scenarios 2 (11.9%), 3 (8.9%), 4 (7.4%), 5 (6.0%), and 6 (1.7%). In terms of feed costs, costs would increase by 41.8% in Scenario 1, followed by Scenarios 2 (37.0%), 3 (34.9%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

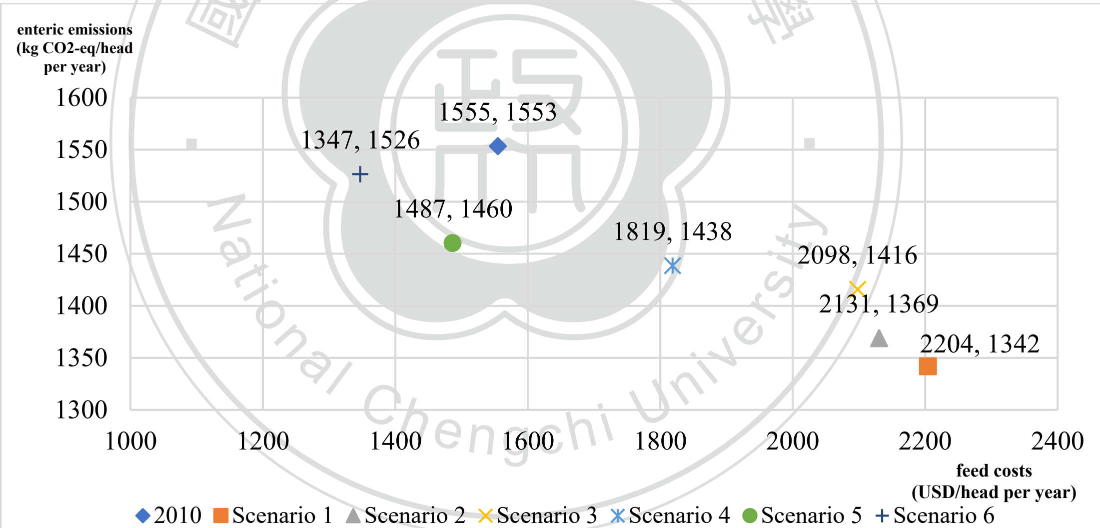

Figure 6: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in mixed systems from dairy cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.2 Beef cattle

Section 6.2 shows enteric emissions and feed costs of six scenarios from different groups. We analyzed these six scenarios in terms of enteric emissions (kg CO_2-eq), feed costs (USD), and costs per unit of mitigating emissions (USD/kg CO_2-eq). Part 1 shows AF in grassland systems, Part 2 shows AM, RF, and RM in grassland systems, Part 3 shows AF in mixed systems, and Part 4 shows AM, RF, and RM in mixed systems.

6.2.1 AF in grassland-based systems

Table 19(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 63.9%, followed by Scenarios 2 (63.4%), 3 (62.3%), 4 (61.8%), 5 (61.5%), and 6 (60.3%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (40.0 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (38.7 MJ/year), followed by Scenarios 4 (38.2), 3 (37.8), 2 (36.9), and 1 (36.4). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (6.2 kg DM), followed by Scenarios 5 (6.1 kg), 4 (5.9), 3 (5.9), 2 (5.8), and 1 (5.6). The ration with lower average digestibility and higher DMI increase enteric emissions.

Table 19(a). Emissions factors of scenarios for AF in grassland systems from beef cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.5	59.5	40.5	6.3	1680
Scenario 1	9.5	63.9	36.4	5.6	1461
Scenario 2	10.8	63.4	36.9	5.8	1489
Scenario 3	9.5	62.3	37.8	5.9	1538
Scenario 4	9.5	61.8	38.2	5.9	1562
Scenario 5	10.8	61.5	38.7	6.1	1584
Scenario 6	11.5	60.3	40.0	6.2	1653

Source: Calculated and collected from GLEAM-i

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Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 19(b) shows the feed intake in different scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 19(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India

Table 19(b). Feed intake in scenarios for AF in grassland systems from beef cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	842 (248)	867 (204)	2112 (344)
Scenario 1	751 (221)	773 (182)	3331 (543)
Scenario 2	775 (229)	798 (188)	3184 (519)
Scenario 3	0 (0)	814 (191)	3417 (557)
Scenario 4	794 (234)	1698 (399)	1991 (325)
Scenario 5	808 (238)	832 (195)	2027 (330)
Scenario 6	0 (0)	855 (201)	2084 (340)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 19(c). Feed costs in scenarios for AF in grassland systems from beef cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	209	167	1352	1728
Scenario 1	186	149	2132	2468
Scenario 2	192	154	2038	2384
Scenario 3	0	157	2187	2344
Scenario 4	197	559	1275	2031
Scenario 5	201	161	1297	1658
Scenario 6	0	165	1334	1499

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would increase the costs of maize silage above that of grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 42.8%, followed by Scenarios 2 (37.9%), 3 (35.6%), and 4 (17.5%). Scenario 5 would reduce feed costs by 4.1% and Scenario 6 would reduce costs by 13.3%.

Figure 7 shows emissions and costs per head in 2010. In terms of mitigation potential, Scenario 1 presents the best choice. Scenario 1 could reduce enteric emissions by 13.1%, followed by Scenarios 2 (11.4%), 3 (8.5%), 4 (7.1%), 5 (5.7%), and 6 (1.6%). In terms of feed costs, these would increase by 42.8% in Scenario 1, followed by Scenarios 2 (37.9%), 3 (35.6%), and 4 (17.5%). Scenario 5 would reduce feed costs by 4.1% and Scenario 6 would reduce feed costs by 13.3%.

Combining the mitigation potential and feed costs of alternative rations, scenario 6 would be the best choice (0.9 USD/kg CO_2-eq), followed by scenario 5 (1.0), scenario 4 (1.3), scenario 3 (1.5), scenario 2 (1.6), and scenario 1 (1.7).

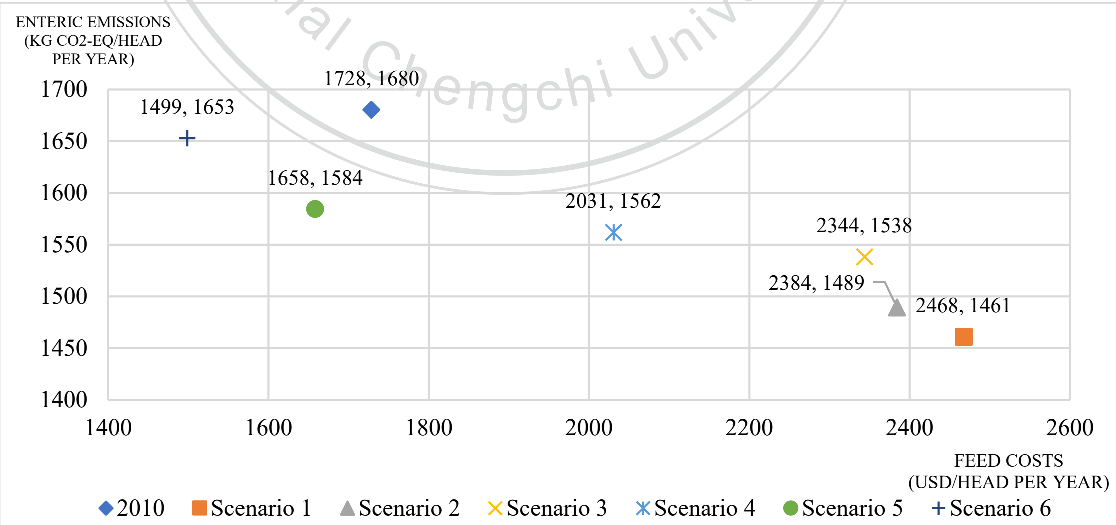

Figure 7: Enteric emissions and feed costs per head in 2010 for AF in grassland systems from beef cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.2.2 AM, RF, and RM in grassland-based systems

Table 20(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 63.9%, followed by Scenarios 2 (63.4%), 3 (62.3%), 4 (61.8%), 5 (61.5%), and 6 (60.3%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (28.3 MJ/year). Cattle would need a higher energy requirement in Scenario 5 (27.3 MJ/year), followed by Scenarios 4 (26.9), 3 (26.6), 2 (25.9), and 1 (25.5). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (4.4 kg DM), followed by Scenarios 5 (4.3 kg), 4 (4.2), 3 (4.2), 2 (4.1), and 1 (3.9). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 20(b) shows the feed intake in different scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 20(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 20(a). Emissions factors of scenarios for AM, RF, and RM in grassland systems from beef cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.5	59.5	28.7	4.5	1191
Scenario 1	9.5	63.9	25.5	3.9	1023
Scenario 2	10.8	63.4	25.9	4.1	1045
Scenario 3	9.5	62.3	26.6	4.2	1082
Scenario 4	9.5	61.8	26.9	4.2	1100
Scenario 5	10.8	61.5	27.3	4.3	1117
Scenario 6	11.5	60.3	28.3	4.4	1170

Source: Calculated and collected from GLEAM-i

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the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would increase the costs of maize silage above that of grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 41.0%, followed by Scenarios 2 (36.5%), 3 (34.5%), and 4 (16.6%). Scenario 5 would reduce feed costs by 4.6% and Scenario 6 would reduce

Table 20(b). Feed intake in scenarios for AM, RF, and RM in grassland systems from beef cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	597 (176)	615 (144)	1498 (244)
Scenario 1	526 (155)	541 (127)	2333 (380)
Scenario 2	544 (160)	560 (132)	2233 (364)
Scenario 3	0 (0)	573 (135)	2403 (392)
Scenario 4	559 (165)	1195 (281)	1402 (229)
Scenario 5	570 (168)	586 (138)	1429 (233)
Scenario 6	0 (0)	605 (142)	1475 (240)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 20(c). Feed costs in scenarios for AM, RF, and RM in grassland systems from beef cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	148	119	958	1225
Scenario 1	131	105	1493	1728
Scenario 2	135	108	1429	1672
Scenario 3	0	111	1538	1648
Scenario 4	139	393	897	1429
Scenario 5	141	113	914	1169
Scenario 6	0	117	944	1061

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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feed costs by 13.4%.

Figure 8 shows emissions and costs per head in 2010. In terms of mitigation potential, Scenario 1 presents the best choice. Scenario 1 could reduce enteric emissions by 14.1%, followed by Scenarios 2 (12.3%), 3 (9.2%), 4 (7.7%), 5 (6.2%), and 6 (1.8%). In terms of feed costs, these would increase by 41.0% in Scenario 1, followed by Scenarios 2 (36.5%), 3 (34.5%), and 4 (16.6%). Scenario 5 would reduce feed costs by 4.6% and Scenario 6 would reduce feed costs by 13.4%.

Combing the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.7).

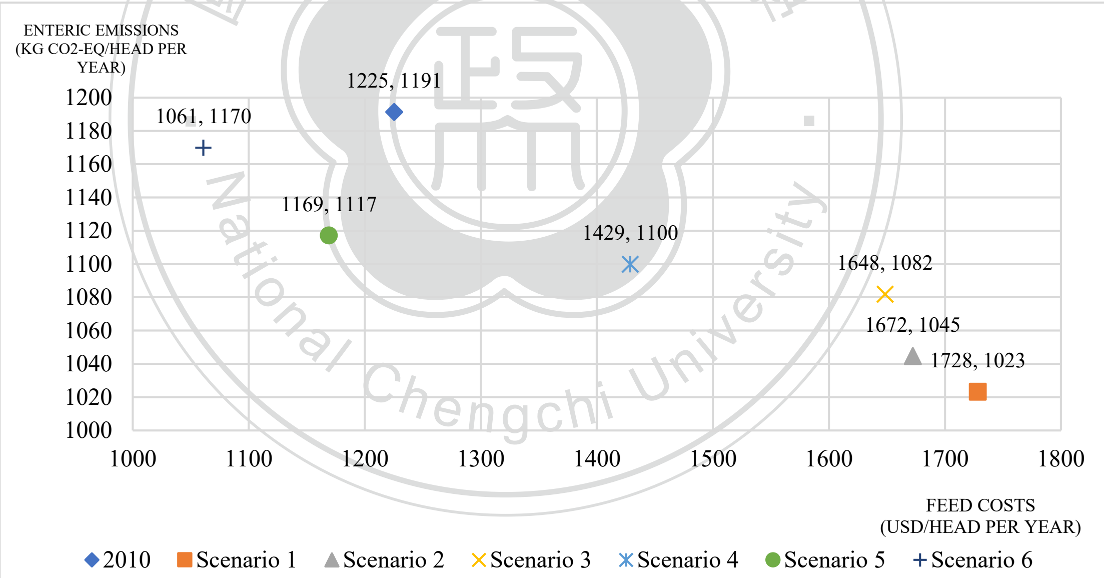

Figure 8: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in grassland systems from beef cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.2.3 AF in mixed farming systems

Table 21(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.2%, followed by Scenarios 2 (63.7%), 3 (62.7%), 4 (62.2%), 5 (61.9%), and 6 (60.7%). If cattle were fed with Scenario 6, they would need the highest energy requirement per year (42.6 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (41.3 MJ/year), followed by Scenarios 4 (40.9), 3 (40.4), 2 (39.5), and 1 (38.5). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (6.6 kg DM), followed by Scenarios 5 (6.5 kg), 4 (6.4), 3 (6.3), 2 (6.2), and 1 (6.0). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 21(b) shows the feed intake of different scenarios. No matter how high the DMI of feed materials is in different scenarios, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 21(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 21(a). Emissions factors of scenarios for AF in mixed systems from beef cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.0	43.1	6.7	1785
Scenario 1	9.2	64.2	38.9	6.0	1560
Scenario 2	10.5	63.7	39.5	6.2	1590
Scenario 3	9.2	62.7	40.4	6.3	1640
Scenario 4	9.2	62.2	40.9	6.4	1664
Scenario 5	10.5	61.9	41.3	6.5	1687
Scenario 6	11.2	60.7	42.6	6.6	1757

Source: Calculated and collected from GLEAM-i

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the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, the total costs would increase by 43.4%, followed by Scenarios 2 (38.4%), 3 (36.0%), and 4 (17.8%). Scenario 5 would reduce feed costs by 3.9% and Scenario 6 would reduce feed costs by 13.2%.

Table 21(b). Feed intake in scenarios for AF in mixed systems from beef cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	871 (257)	896 (211)	2184 (356)
Scenario 1	780 (230)	803 (189)	3460 (564)
Scenario 2	804 (237)	828 (195)	3303 (538)
Scenario 3	0 (0)	844 (198)	3542 (577)
Scenario 4	823 (243)	1760 (414)	2064 (336)
Scenario 5	837 (247)	862 (202)	2099 (342)
Scenario 6	0 (0)	885 (208)	2156 (351)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 21(c). Feed costs in scenarios for AF in mixed systems from beef cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	216	173	1398	1787
Scenario 1	194	155	2215	2563
Scenario 2	200	160	2114	2474
Scenario 3	0	163	2267	2430
Scenario 4	204	580	1321	2105
Scenario 5	208	166	1344	1718
Scenario 6	0	171	1380	1551

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

Figure 9 shows emissions and costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it would reduce enteric emissions by 12.6%, followed by Scenarios 2 (11.0%), 3 (8.1%), 4 (6.8%), 5 (5.5%), and 6 (1.6%). In terms of feed costs, costs would increase the most in Scenario 1 (43.4%), followed by Scenarios 2 (38.4%), 3 (36.0%), and 4 (17.8%). Scenario 5 would reduce feed costs by 3.9% and Scenario 6 would reduce feed costs by 13.2%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

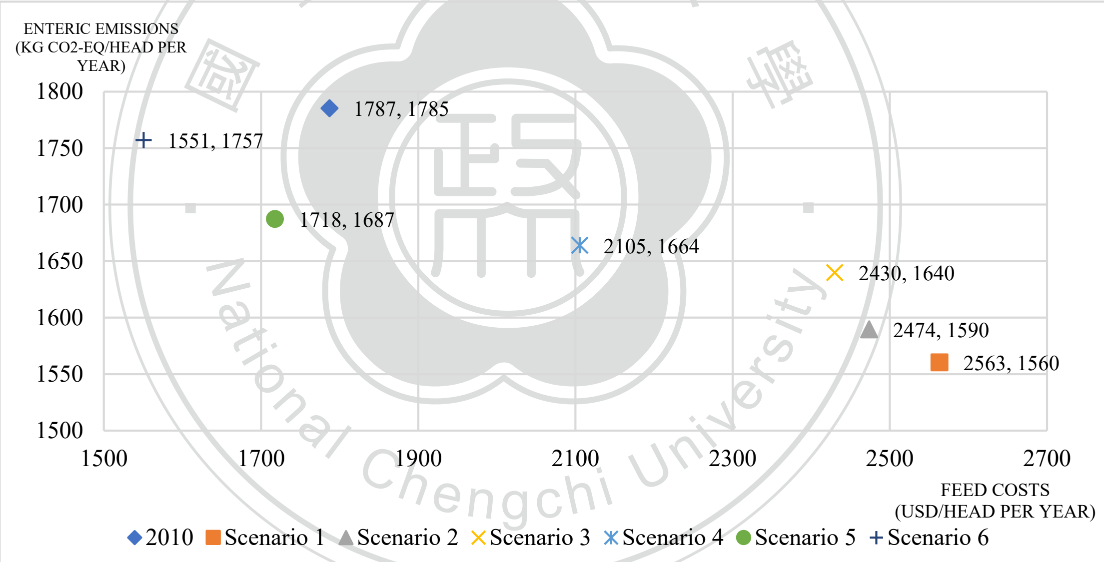

Figure 9: Enteric emissions and feed costs per head in 2010 for AF in mixed systems from beef cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.2.4 AM, RF, and RM in mixed farming systems

Table 22(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.2%, followed by Scenarios 2 (63.7%), 3 (62.7%), 4 (62.2%), 5 (61.9%), and 6 (60.7%). If cattle were fed with scenario 6, they would need the highest energy requirement per year (37.0 MJ/year). Cattle would need a higher gross energy requirement in Scenario 5 (35.7 MJ/year), followed by Scenarios 4 (35.3), 3 (34.9), 2 (34.0), and 1 (33.5). Cattle would need to eat more feed with lower average digestibility to get the same net energy requirement. Cattle would need to eat the most DM per day in Scenario 6 (5.8 kg DM), followed by Scenarios 5 (5.6 kg), 4 (5.5), 3 (5.5), 2 (5.4), and 1 (5.2). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 22(b) shows feed intake in different scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 22(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 22(a). Emissions factors of scenarios for AM, RF, and RM in mixed systems from beef cattle

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.0	37.5	5.9	1553
Scenario 1	9.2	64.2	33.5	5.2	1342
Scenario 2	10.5	63.7	34.0	5.4	1369
Scenario 3	9.2	62.7	34.9	5.5	1416
Scenario 4	9.2	62.2	35.3	5.5	1438
Scenario 5	10.5	61.9	35.7	5.6	1460
Scenario 6	11.2	60.7	37.0	5.8	1526

Source: Calculated and collected from GLEAM-i

DOI:10.6814/NCCU202000300

the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 41.8%, followed by Scenarios 2 (37.0%), 3 (34.9%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and

Table 22(b). Feed intake in scenarios for AM, RF, and RM in mixed systems from beef cattle (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	758 (224)	780 (183)	1900 (310)
Scenario 1	671 (198)	690 (162)	2976 (485)
Scenario 2	693 (204)	713 (168)	2845 (464)
Scenario 3	0 (0)	729 (171)	3058 (499)
Scenario 4	711 (210)	1521 (357)	1784 (291)
Scenario 5	724 (214)	746 (175)	1817 (296)
Scenario 6	0 (0)	769 (181)	1873 (305)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 22(c). Feed costs in scenarios for AM, RF, and RM in mixed systems from beef cattle (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	188	151	1216	1555
Scenario 1	166	133	1905	2204
Scenario 2	172	138	1821	2131
Scenario 3	0	141	1957	2098
Scenario 4	177	500	1142	1819
Scenario 5	180	144	1163	1487
Scenario 6	0	148	1199	1347

Note: Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

Scenario 6 would reduce feed costs by 13.4%.

Figure 10 shows emissions and costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 13.6%, followed by Scenarios 2 (11.9%), 3 (8.9%), 4 (7.4%), 5 (6.0%), and 6 (1.7%). In terms of feed costs, costs would increase by 41.8% in Scenario 1, followed by Scenarios 2 (37.0%), 3 (34.9%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

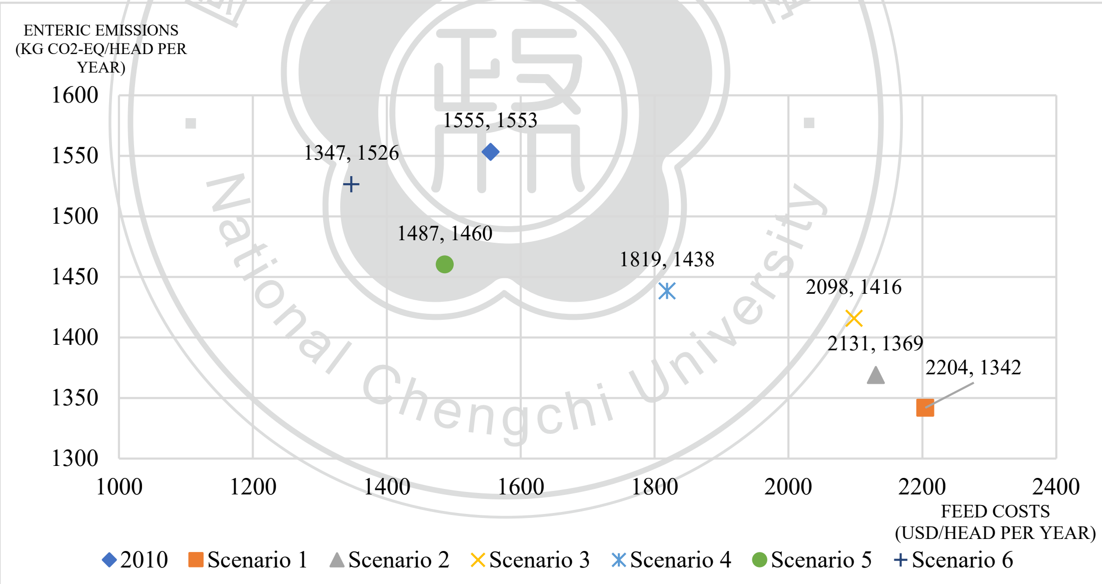

Figure 10: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in mixed systems from beef cattle
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.3 Dairy buffalo

Section 6.3 shows the enteric emissions and feed costs of six scenarios from different groups. We analyzed these six scenarios in terms of enteric emissions (kg CO_2-eq), feed costs (USD), and costs per unit of mitigating emissions (USD/kg CO_2-eq). Part 1 shows AF in grassland systems, Part 2 shows AM, RF, and RM in grassland systems, Part 3 shows AF in mixed systems, and Part 4 shows AM, RF, and RM in mixed systems.

6.3.1 AF in grassland-based systems

Table 23(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 66.1%, followed by Scenarios 2 (65.6%), 3 (64.8%), 4 (64.3%), 5 (64.1%), and 6 (63%). If buffalo were fed with Scenario 6, they would need the highest energy requirement per year (77.6 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (75.6 MJ/year), followed by Scenarios 4 (74.9), 3 (74.2), 2 (72.8), and 1 (71.9). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement.

Buffalo would need to eat the most DM per day in Scenario 6 (11.9 kg DM), followed by Scenarios 5 (11.6 kg), 4 (11.5), 3 (11.5), 2 (11.3), and scenario 1 (11.0).

Table 23(a). Emissions factors of scenarios for AF in grassland systems from dairy buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	10.0	62.3	78.4	12.0	3186
Scenario 1	8.3	66.1	71.9	11.0	2839
Scenario 2	9.4	65.6	72.8	11.3	2885
Scenario 3	8.3	64.8	74.2	11.5	2963
Scenario 4	8.3	64.3	74.9	11.5	3001
Scenario 5	9.4	64.1	75.6	11.6	3036
Scenario 6	10.0	63.0	77.6	11.9	3144

Source: Calculated and collected from GLEAM-i

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The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 23(b) shows feed intake in different scenarios. No matter how high the DMI of feed materials in different scenarios, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and then grain silage.

Table 23(c) shows the feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize

Table 23(b) Feed intake in scenarios for AF in grassland systems from dairy buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	1394 (411)	1435 (337)	3496 (570)
Scenario 1	1270 (375)	1307 (307)	5636 (919)
Scenario 2	1305 (385)	1343 (316)	5358 (873)
Scenario 3	0 (0)	1365 (321)	5727 (933)
Scenario 4	1330 (392)	2843 (668)	3335 (544)
Scenario 5	1349 (398)	1388 (326)	3383 (551)
Scenario 6	0 (0)	1419 (334)	3458 (564)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 23(c). Feed costs in scenarios for AF in grassland systems from dairy buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	346	277	2238	2861
Scenario 1	315	252	3607	4175
Scenario 2	324	259	3429	4013
Scenario 3	180	144	1901	2224
Scenario 4	330	941	2134	3405
Scenario 5	335	268	2165	2768
Scenario 6	0	274	2213	2487

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would make the costs of maize silage higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 45.9%, followed by Scenarios 2 (40.3%), 3 (37.3%), and 4 (19.0%). Scenario 5 would reduce feed costs by 3.2% and Scenario 6 would reduce feed costs by 13.0%.

Figure 11 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 10.9%, followed by Scenarios 2 (9.5%), 3 (7.0%), 4 (5.8%), 5 (4.7%), and 6 (1.3%). In terms of feed costs, costs would increase by 45.9% in Scenario 1, followed by Scenarios 2 (40.3%), 3 (37.3%), and 4 (19.0%). Scenario 5 would reduce feed costs by 3.2% and Scenario 6 would reduce feed costs by 13.0%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.8 USD/kg CO_2-eq), followed by Scenarios 5 (0.9), 4 (1.1), o 3 (1.3), 2 (1.4), and 1 (1.5).

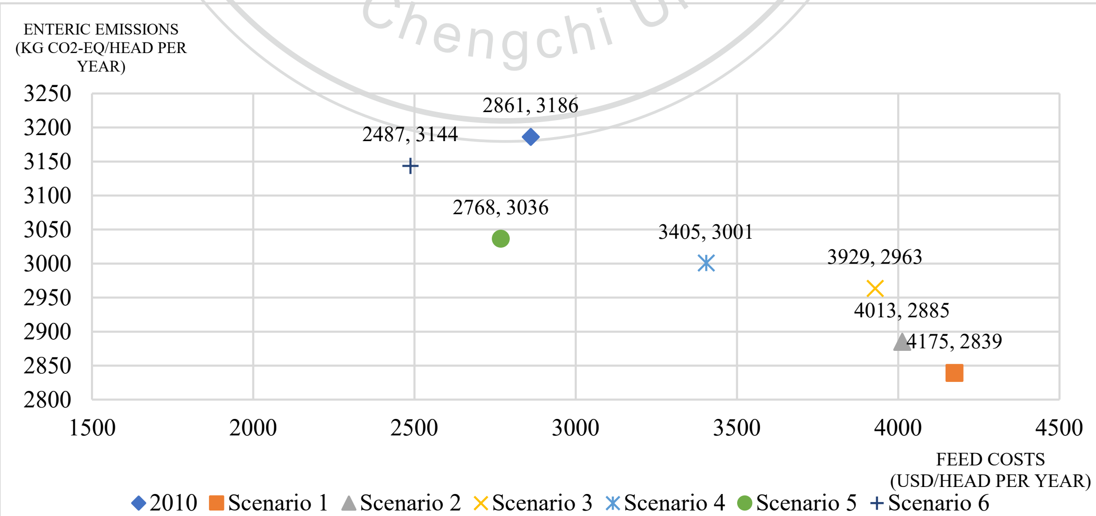

Figure 11: Enteric emissions and feed costs per head in 2010 for AF in grassland systems from dairy buffalo
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.3.2 AM, RF, and RM in grassland-based systems

Table 24(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.4%, followed by Scenarios 2 (63.9%), 3 (62.9%), 4 (62.4%), 5 (62.1%), and 6 (60.9%). If buffalo were fed with Scenario 6, they would need the highest energy requirement per year (38.9 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (37.6 MJ/year), followed by Scenarios 4 (37.1), 3 (36.7), 2 (35.7), and 1 (35.2). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (6.0 kg DM), followed by Scenarios 5 (5.8 kg), 4 (5.7), 3 (5.7), 2 (5.6), and 1 (5.4). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 24(b) shows feed intake in different scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 24(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 24(a). Emissions factors of scenarios for AM, RF, and RM in grassland systems from dairy buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.2	39.5	6.1	1631
Scenario 1	9.2	64.4	35.2	5.4	1407
Scenario 2	10.5	63.9	35.7	5.6	1435
Scenario 3	9.2	62.9	36.7	5.7	1485
Scenario 4	9.2	62.4	37.1	5.7	1509
Scenario 5	10.5	62.1	37.6	5.8	1532
Scenario 6	11.2	60.9	38.9	6.0	1602

Source: Calculated and collected from GLEAM-i

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the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would increase the costs of maize silage above that of grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 41.6%, followed by Scenarios 2 (36.8%), 3 (34.8%), and 4 (16.9%). Scenario 5 would reduce feed costs by 4.5% and Scenario 6 would reduce

Table 24(b). Feed intake in scenarios for AM, RF, and RM in grassland systems from dairy buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	792 (234)	815 (192)	1987 (324)
Scenario 1	700 (207)	721 (169)	3107 (506)
Scenario 2	723 (213)	744 (175)	2907 (484)
Scenario 3	0 (0)	761 (179)	3194 (521)
Scenario 4	743 (219)	1589 (373)	1864 (304)
Scenario 5	757 (223)	779 (183)	1898 (309)
Scenario 6	0 (0)	803 (189)	1957 (319)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 24(c). Feed costs in scenarios for AM, RF, and RM in grassland systems from dairy buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	197	157	1271	1626
Scenario 1	174	139	1988	2301
Scenario 2	0	264	3665	3929
Scenario 3	0	147	2044	2191
Scenario 4	184	522	1193	1899
Scenario 5	188	150	1215	1553
Scenario 6	0	155	1253	1408

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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feed costs by 13.4%.

Figure 12 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 presents the best choice. Scenario 1 could reduce enteric emissions by 13.7%, followed by Scenarios 2 (12.0%), 3 (8.9%), 4 (7.5%), 5 (6.1%), and scenario 6 (1.7%). In terms of feed costs, costs would increase by 41.6% in Scenario 1, followed by Scenarios 2 (36.8%), 3 (34.8%), and 4 (16.9%). Scenario 5 would reduce feed costs by 4.5% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

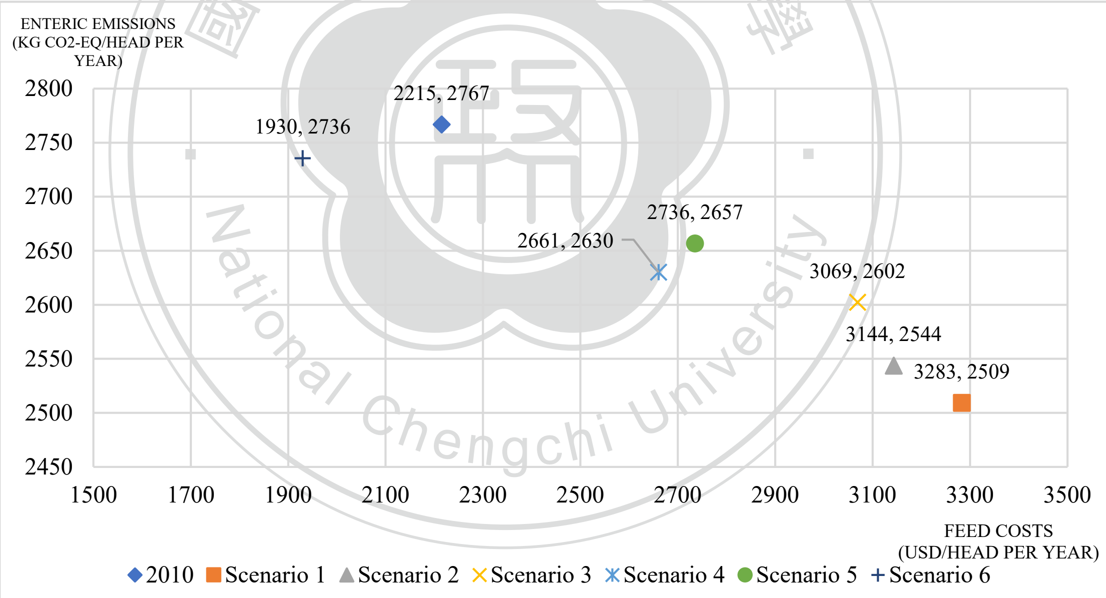

Figure 12: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in grassland systems from dairy buffalo

Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.3.3 AF in mixed farming systems

Table 25(a) shows the emissions factors of different scenarios. The ration with the best average digestibility would be Scenario 1. The average digestibility of Scenario 1 is 68.1%, followed by Scenarios 2 (67.7%), 3 (66.9%), 4 (66.5%), 5 (66.3%), and 6 (65.3%). If buffalo were fed with Scenario 6, they would need the highest energy requirement per year (68.7 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (67.3 MJ/year), followed by Scenarios 4 (66.8), 3 (66.3), 2 (65.2), and 1 (64.5). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (10.5 kg DM), followed by Scenarios 5 (10.3kg), 4 (10.2), 3 (10.1), 2 (10.0), and 1 (9.8). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed material and feed intake in terms of kg. Table 25(b) shows feed intake of different scenarios. No matter how high the DMI of feed materials is in different scenarios, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 25(a). Emissions factors of scenarios for AF in mixed systems from dairy buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	8.8	64.7	69.3	10.6	2767
Scenario 1	7.3	68.1	64.5	9.8	2509
Scenario 2	8.3	67.7	65.2	10.0	2544
Scenario 3	7.3	66.9	66.3	10.1	2602
Scenario 4	7.3	66.5	66.8	10.2	2630
Scenario 5	8.3	66.3	67.3	10.3	2657
Scenario 6	8.8	65.3	68.7	10.5	2736

Source: Calculated and collected from GLEAM-i

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Table 25(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 48.2%, followed by Scenarios 2 (41.9%), 3 (38.5%), and 4 (20.1%). Scenario 5 would reduce feed costs by 2.7% and

Table 25(b). Feed intake in scenarios for AF in mixed systems from dairy buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	1080 (318)	1111 (261)	2708 (441)
Scenario 1	999 (295)	1028 (242)	4433 (723)
Scenario 2	1022 (302)	1052 (247)	4198 (684)
Scenario 3	0 (0)	1067 (251)	4474 (729)
Scenario 4	1038 (306)	2219 (522)	2603 (424)
Scenario 5	1051 (310)	1082 (254)	2635 (430)
Scenario 6	0 (0)	1101 (259)	2683 (437)

Note: The data in parentheses means DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 25(c). Feed costs in scenarios for AF in mixed systems from dairy buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	268	215	1733	2215
Scenario 1	248	199	2837	3283
Scenario 2	254	203	2687	3144
Scenario 3	0	206	2863	3069
Scenario 4	258	737	1666	2661
Scenario 5	261	209	1687	2156
Scenario 6	0	213	1717	1930

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

Scenario 6 would reduce feed costs by 12.9%.

Figure 13 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it would reduce enteric emissions by 9%, followed by Scenarios 2 (8%), 3 (6%), 4 (5%), 5 (4%), and 6 (1%). In terms of feed costs, costs would increase the most in Scenario 1 (48.2%), followed by Scenarios 2 (41.9%), 3 (38.5%), and 4 (20.1%). Scenario 5 would reduce feed costs by 2.7% and Scenario 6 would reduce feed costs by 12.9%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.7 USD/kg CO_2 -eq), followed by Scenarios 5 (0.8), 4 (1.0), 3 (1.2), 2 (1.2), and 1 (1.3).

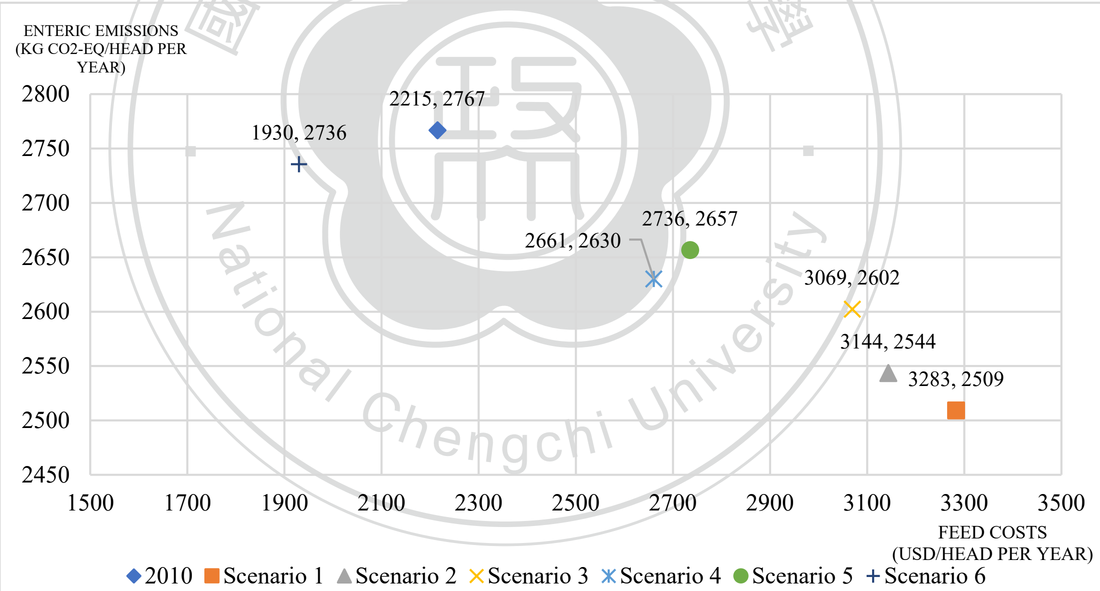

Figure 13: Enteric emissions and feed costs per head in 2010 for AF in mixed systems from dairy buffalo
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.3.4 AM, RF, and RM in mixed farming systems

Table 26(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.3%, followed by Scenarios 2 (63.7%), 3 (62.8%), 4 (62.3%), 5 (62.0%), and 6 (60.8%). If buffalo were fed with scenario 6, they would need the highest energy requirement per year (36.4 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (35.1 MJ/year), followed by Scenarios 4 (34.7), 3 (34.3), 2 (33.4), and 1 (32.8). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (5.6 kg DM), followed by Scenarios 5 (5.5 kg), 4 (5.4), 3 (5.3), 2 (5.2), and 1 (5.1). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 26(b) shows feed intake in different Scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beets would be the highest, followed by maize silage and grain silage.

Table 26(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be

Table 26(a). Emissions factors of scenarios for AM, RF, and RM in mixed systems from dairy buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.0	36.9	5.7	1528
Scenario 1	9.2	64.3	32.8	5.1	1316
Scenario 2	10.5	63.7	33.4	5.2	1343
Scenario 3	9.2	62.8	34.3	5.3	1390
Scenario 4	9.2	62.3	34.7	5.4	1413
Scenario 5	10.5	62.0	35.1	5.5	1435
Scenario 6	11.2	60.8	36.4	5.6	1501

Source: Calculated and collected from GLEAM-i

DOI:10.6814/NCCU202000300

the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 41.3%, followed by Scenarios 2 (36.6%), 3 (34.6%), and 4 (16.7%). Scenario 5 would reduce feed costs by 4.5% and

Table 26(b). Feed intake in scenarios for AM, RF, and RM in mixed systems from dairy buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	741 (219)	763 (179)	1859 (303)
Scenario 1	654 (193)	673 (158)	2902 (473)
Scenario 2	676 (199)	696 (163)	2775 (452)
Scenario 3	0 (0)	712 (167)	2985 (487)
Scenario 4	695 (205)	1485 (349)	1742 (284)
Scenario 5	708 (209)	728 (171)	1775 (289)
Scenario 6	0 (0)	752 (177)	1831 (299)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 26(c). Feed costs in scenarios for AM, RF, and RM in mixed systems from dairy buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	184	147	1190	1521
Scenario 1	162	130	1857	2149
Scenario 2	168	134	1776	2078
Scenario 3	0	137	1910	2048
Scenario 4	172	488	1115	1776
Scenario 5	176	141	1136	1452
Scenario 6	0	145	1172	1317

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

Scenario 6 would reduce feed costs by 13.4%.

Figure 14 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 13.9%, followed by Scenarios 2 (12.1%), 3 (9.1%), 4 (7.6%), 5 (6.1%), and 6 (1.8%). In terms of feed costs, costs would increase by 41.3% in Scenario 1, followed by Scenarios 2 (36.6%), 3 (34.6%), and 4 (16.7%). Scenario 5 would reduce feed costs by 4.5% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

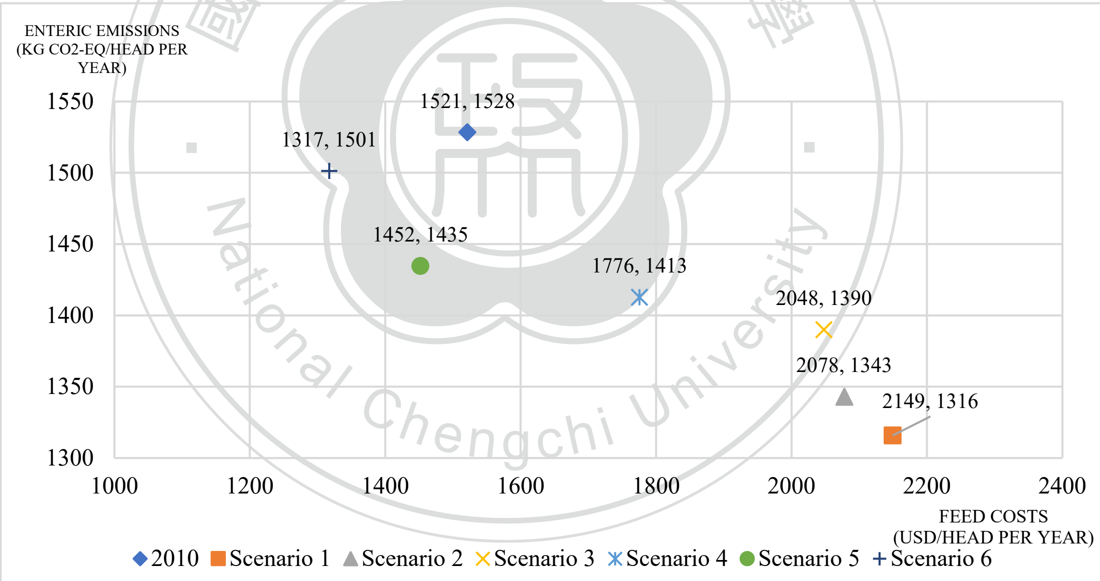

Figure 14: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in mixed systems from dairy buffalo
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.4 Beef buffalo

Section 6.4 shows the enteric emissions and feed costs of six scenarios from different groups. We analyzed these six scenarios in terms of enteric emissions (kg CO_2 -eq), feed costs (USD), and costs per unit of mitigating emissions (USD/kg CO_2 -eq). Part 1 shows AF in grassland systems, Part 2 shows AM, RF, and RM in grassland systems, Part 3 shows AF in mixed systems, and Part 4 shows AM, RF, and RM in mixed systems.

6.4.1 AF in grassland-based systems

Table 27(a) shows the emissions factors of different scenarios. The ration with the best average digestibility would be Scenario 1. The average digestibility of Scenario 1 is 64.4%, followed by Scenarios 2 (63.9%), 3 (62.9%), 4 (62.4%), 5 (62.1%), and 6 (60.9%). If buffalo were fed with scenario 6, they would need the highest energy requirement per year (57.6 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (55.8 MJ/year), followed by Scenarios 4 (55.2), 3 (54.6), 2 (53.4), and 1 (52.6). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (8.9 kg DM), followed by Scenarios 5 (8.7 kg), 4 (8.5), 3 (8.5), 2 (8.4), and 1 (8.1). The ration with lower average digestibility and higher DMI

Table 27(a). Emissions factors of scenarios for AF in grassland systems from beef buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2 -eq/year
2010	11.2	60.2	58.3	9.0	2408
Scenario 1	9.2	64.4	52.6	8.1	2106
Scenario 2	10.5	63.9	53.4	8.4	2146
Scenario 3	9.2	62.9	54.6	8.5	2213
Scenario 4	9.2	62.4	55.2	8.5	2246
Scenario 5	10.5	62.1	55.8	8.7	2277
Scenario 6	11.2	60.9	57.6	8.9	2370

Source: Calculated and collected from GLEAM-i

DOI:10.6814/NCCU202000300

increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 27(b) shows feed intake in different scenarios. No matter how high the DMI of feed materials in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and then grain silage.

Table 27(c) shows the feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg.

Table 27(b). Feed intake in scenarios for AF in grassland systems from beef buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	1170 (345)	1204 (283)	2934 (478)
Scenario 1	1048 (309)	1079 (254)	4652 (758)
Scenario 2	1081 (319)	1113 (262)	4440 (724)
Scenario 3	0 (0)	1135 (267)	4760 (776)
Scenario 4	1106 (326)	2364 (556)	2774 (452)
Scenario 5	802 (332)	1715 (272)	2012 (460)
Scenario 6	0 (0)	1188 (279)	2896 (472)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 27(c). Feed costs in scenarios for AF in grassland systems from beef buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	290	232	1878	2400
Scenario 1	260	208	2977	3446
Scenario 2	268	215	2841	3325
Scenario 3	0	219	3046	3265
Scenario 4	274	780	1775	2829
Scenario 5	279	224	1805	2308
Scenario 6	0	229	1853	2083

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

DOI:10.6814/NCCU202000300

The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would make the costs of maize silage higher than grain silage in Scenario 4. In Scenario 1, the total costs would increase by 43.5%, followed by Scenarios 2 (38.5%), 3 (36.0%), and 4 (17.9%). Scenario 5 would reduce feed costs by 3.9% and Scenario 6 would reduce feed costs by 13.2%.

Figure 15 shows the enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 12.5%, followed by Scenarios 2 (10.9%), 3 (8.1%), 4 (6.8%), 5 (5.5%), and 6 (1.6%). In terms of feed costs, costs would increase by 43.5% in Scenario 1, followed by Scenarios 2 (38.5%), 3 (36.0%), and 4 (17.9%). Scenario 5 would reduce feed costs by 3.9%. Scenario 6 would reduce feed costs by 13.2%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

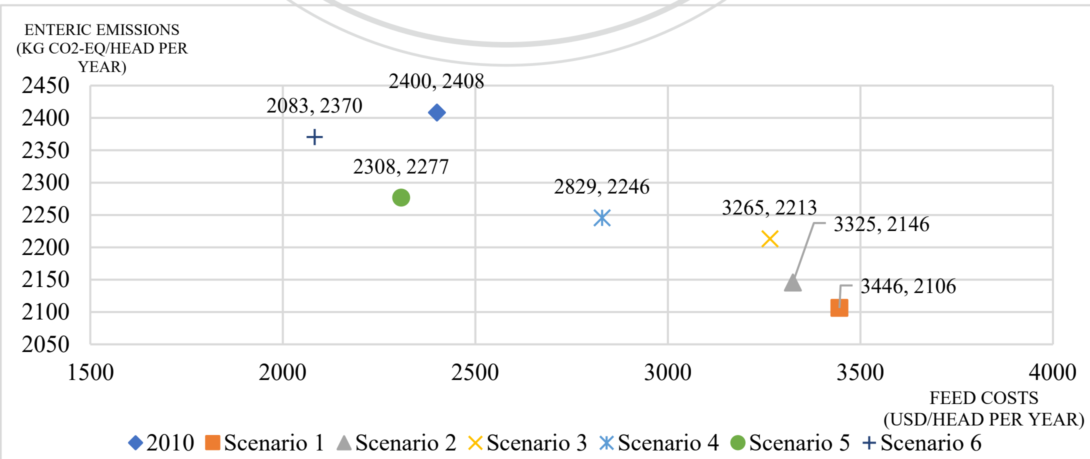

Figure 15: Enteric emissions and feed costs per head in 2010 for AF in grassland systems from beef buffalo
Source: Calculated and collected from GLEAM-i and FAOSTAT

DOI:10.6814/NCCU202000300

6.4.2 AM, RF, and RM in grassland-based systems

Table 28(a) shows the emissions factors of different scenarios. The ration with the best average digestibility would be Scenario 1. The average digestibility of Scenario 1 is 64.4%, followed by Scenarios 2 (63.9%), 3 (62.9%), 4 (62.4%), 5 (62.1%), and 6 (60.9%). If buffalo were fed with Scenario 6, they need the highest energy requirement per year (41.9 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (40.5 MJ/year), followed by Scenarios 4 (40.1), 3 (39.6), 2 (38.6), and 1 (38.0). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (6.5 kg DM), followed by Scenarios 5 (6.3 kg), 4 (6.2), 3 (6.2), 2 (6), and 1 (5.8). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 28(b) shows the feed intake in different scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 28(a). Emissions factors of scenarios for AM, RF, and RM in grassland systems from beef buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.2	42.5	6.6	1756
Scenario 1	9.2	64.4	38.0	5.8	1521
Scenario 2	10.5	63.9	38.6	6.0	1551
Scenario 3	9.2	62.9	39.6	6.2	1603
Scenario 4	9.2	62.4	40.1	6.2	1629
Scenario 5	10.5	62.1	40.5	6.3	1653
Scenario 6	11.2	60.9	41.9	6.5	1727

Source: Calculated and collected from GLEAM-i

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Table 28(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only in Scenario 4 would maize silage be imported to India due to the higher intake than the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would increase the costs of maize silage above that of grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 42.1%, followed by Scenarios 2 (37.3%), 3 (35.1%), and

Table 28(b). Feed intake in scenarios for AM, RF, and RM in grassland systems from beef buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	853 (252)	878 (206)	2140 (349)
Scenario 1	757 (223)	779 (183)	3358 (547)
Scenario 2	782 (231)	804 (189)	3209 (523)
Scenario 3	0 (0)	822 (193)	3448 (562)
Scenario 4	1125 (237)	1158 (403)	2820 (328)
Scenario 5	816 (241)	840 (197)	2048 (334)
Scenario 6	0 (0)	866 (203)	2109 (344)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 28(c). Feed costs in scenarios for AM, RF, and RM in grassland systems from beef buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	212	170	1369	1751
Scenario 1	188	150	2149	2488
Scenario 2	194	155	2054	2403
Scenario 3	0	159	2207	2366
Scenario 4	199	564	1287	2051
Scenario 5	203	162	1310	1675
Scenario 6	0	167	1350	1517

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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4 (17.1%). Scenario 5 would reduce feed costs by 4.3% and Scenario 6 would reduce feed costs by 13.3%.

Figure 16 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 presents the best choice. Scenario 1 could reduce enteric emissions by 13.4%, followed by Scenarios 2 (11.7%), 3 (8.7%), 4 (7.3%), 5 (5.9%), and 6 (1.7%). In terms of feed costs, costs would increase by 42.1% in Scenario 1, followed by Scenarios 2 (37.3%), 3 (35.1%), and 4 (17.1%). Scenario 5 would reduce feed costs by 4.3% and Scenario 6 would reduce fed costs by 13.3%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2 -eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

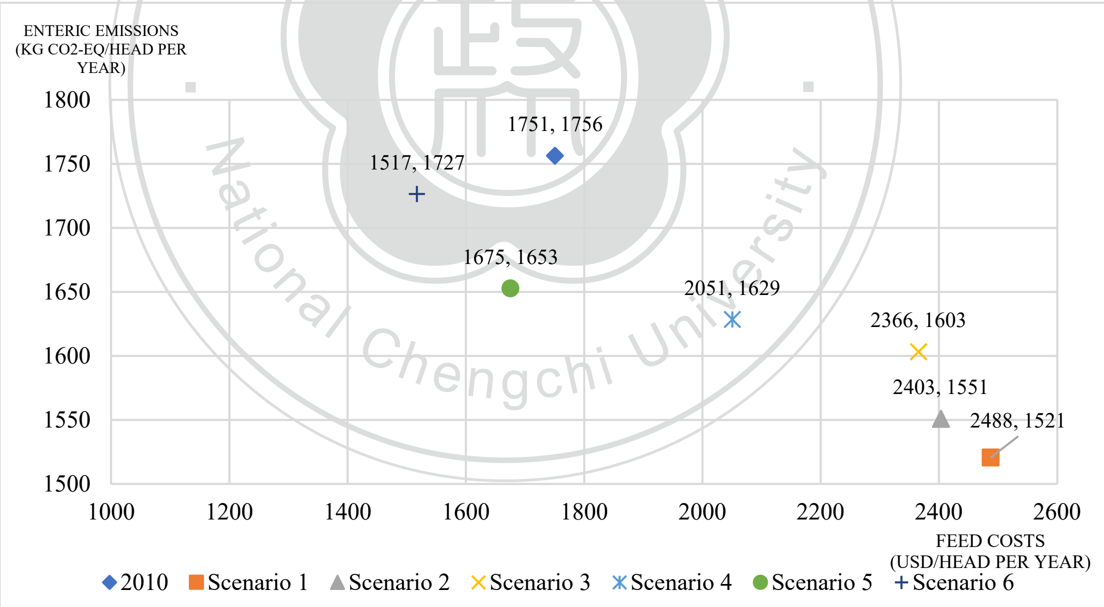

Figure 16: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in grassland systems from beef buffalo

Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.4.3 AF in mixed farming systems

Table 29(a) shows the emissions factors of different scenarios. The ration with the best average digestibility would be Scenario 1. The average digestibility of Scenario 1 is 64.3%, followed by Scenarios 2 (63.7%), 3 (62.8%), 4 (62.3%), 5 (62%), and 6 (60.8%). If buffalo were fed with Scenario 6, they would need the highest energy requirement per year (52.5 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (50.9 MJ/year), followed by Scenarios 4 (50.4), 3 (49.8), 2 (48.7), and 1 (48). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (8.1 kg DM), followed by Scenarios 5 (7.9 kg), 4 (7.8), 3 (7.8), 2 (7.6), and 1 (7.4). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed material and feed intake in terms of kg. Table 29(b) shows feed intake of different scenarios. No matter how high the DMI of feed materials is in different scenarios, feed intake in terms of kg from fodder beet would be the highest, followed by maize silage and grain silage.

Table 29(a). Emissions factors of scenarios for AF in mixed systems from beef buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.0	53.2	8.2	2201
Scenario 1	9.2	64.3	48.0	7.4	1924
Scenario 2	10.5	63.7	48.7	7.6	1960
Scenario 3	9.2	62.8	49.8	7.8	2022
Scenario 4	9.2	62.3	50.4	7.8	2051
Scenario 5	10.5	62.0	50.9	7.9	2080
Scenario 6	11.2	60.8	52.5	8.1	2166

Source: Calculated and collected from GLEAM-i

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Table 29(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In scenario 1, the total feed costs would increase by 43.5%, followed by Scenarios 2

Table 29(b). Feed intake in scenarios for AF in mixed systems from beef buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	1067 (315)	1099 (258)	2677 (436)
Scenario 1	956 (282)	984 (231)	4242 (691)
Scenario 2	986 (291)	1015 (238)	4049 (660)
Scenario 3	0 (0)	1035 (243)	4341 (708)
Scenario 4	1009 (298)	2157 (507)	2530 (412)
Scenario 5	1026 (303)	1056 (248)	2573 (419)
Scenario 6	0 (0)	1084 (255)	2642 (431)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 29(c). Feed costs in scenarios for AF in mixed systems from beef buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	265	212	1713	2190
Scenario 1	237	190	2715	3142
Scenario 2	245	196	2591	3032
Scenario 3	0	200	2779	2978
Scenario 4	250	711	1619	2581
Scenario 5	255	204	1647	2105
Scenario 6	0	209	1691	1900

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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(38.4%), 3 (36.0%), and 4 (17.8%). Scenario 5 would reduce feed costs by 3.9% and Scenario 6 would reduce feed costs by 13.2%.

Figure 17 shows enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it would reduce enteric emissions by 12.6%, followed by Scenarios 2 (10.9%), 3 (8.1%), 4 (6.8%), 5 (5.5%), and 6 (1.6%). In terms of feed costs, costs would increase the most in Scenario 1 (43.5%), followed by Scenarios 2 (38.4%), 3 (36.0%), and 4 (17.8%). Scenario 5 would reduce feed costs by 3.9% and Scenario 6 would reduce feed costs by 13.2%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

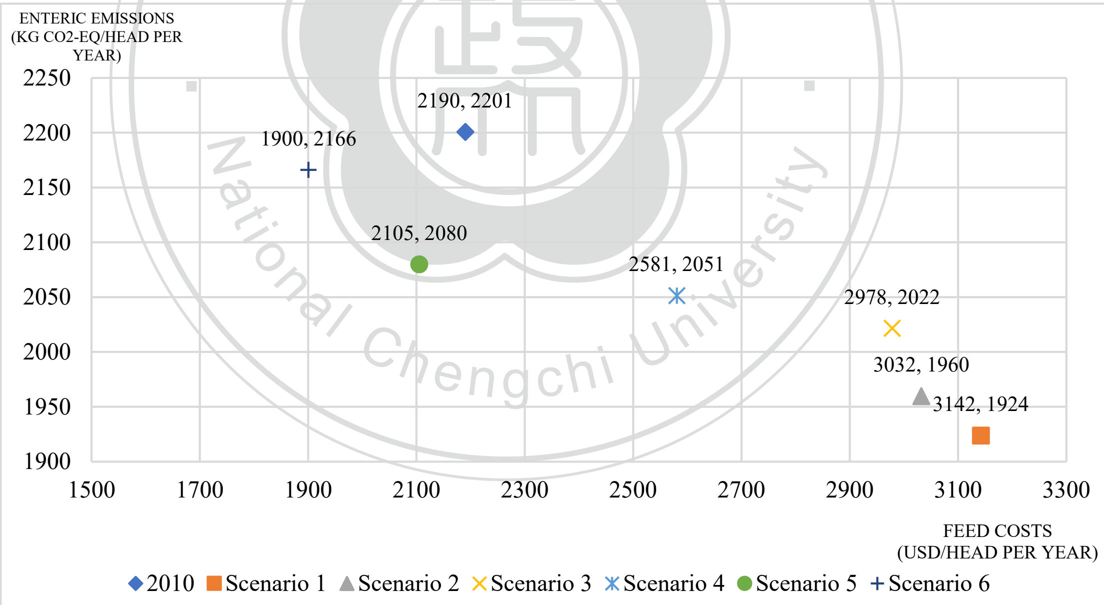

Figure 17: Enteric emissions and feed costs per head in 2010 for AF in mixed systems from beef buffalo
Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.4.4 AM, RF, and RM in mixed farming systems

Table 30(a) shows the emissions factors of different scenarios. Scenario 1 is the ration with the best average digestibility. The average digestibility of Scenario 1 is 64.3%, followed by Scenarios 2 (63.7%), 3 (62.8%), 4 (62.3%), 5 (62.0%), and 6 (60.8%). If buffalo were fed with Scenario 6, they would need the highest energy requirement per year (38.9 MJ/year). Buffalo would need a higher gross energy requirement in Scenario 5 (37.6 MJ/year), followed by Scenarios 4 (37.1), 3 (36.7), 2 (35.8), and 1 (35.2). Buffalo would need to eat more feed with lower average digestibility to get the same net energy requirement. Buffalo would need to eat the most DM per day in Scenario 6 (6.0 kg DM), followed by Scenarios 5 (5.8 kg), 4 (5.7), 3 (5.7), 2 (5.6), and 1 (5.4). The ration with lower average digestibility and higher DMI increase enteric emissions.

Although Scenario 1 could reduce the maximum emissions, it would also be relatively costly. Feed costs depend on the prices of feed materials and feed intake in terms of kg. Table 30(b) shows feed intake in different Scenarios. No matter how high the DMI of feed materials is in Scenarios 1–6, feed intake in terms of kg from fodder beets would be the highest, followed by maize silage and grain silage.

Table 30(a). Emissions factors of scenarios for AM, RF, and RM in mixed systems from beef buffalo

	Percentage change	DIETDI	GEtot	DMI	Enteric emissions
Unit	percentage	percentage	MJ/ year	kg DM/day	kg CO_2-eq/year
2010	11.2	60.0	39.5	6.1	1632
Scenario 1	9.2	64.3	35.2	5.4	1411
Scenario 2	10.5	63.7	35.8	5.6	1439
Scenario 3	9.2	62.8	36.7	5.7	1488
Scenario 4	9.2	62.3	37.1	5.7	1512
Scenario 5	10.5	62.0	37.6	5.8	1535
Scenario 6	11.2	60.8	38.9	6.0	1604

Source: Calculated and collected from GLEAM-i

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Table 30(c) shows feed costs in Scenarios 1–6. The costs of fodder beet would be the highest in all scenarios because it has the highest feed intake and price per kg. The higher price per kg means that the costs of grain silage would be higher than maize silage, except in Scenario 4. Only Scenario 4 requires importing maize silage to India due to the higher intake than in the current situation in 2010. The import price of maize silage would be higher than the domestic price of grain silage, which would be the reason why the costs of maize silage is higher than grain silage in Scenario 4. In Scenario 1, the total feed costs would increase by 41.9%, followed by Scenarios 2

Table 30(b). Feed intake in scenarios for AM, RF, and RM in mixed systems from beef buffalo (kg/head per year)

	Grain silage	Maize silage	Fodder beet
DM content (percentage)	29.3	23.5	16.3
2010	792 (234)	815 (191)	1986 (324)
Scenario 1	701 (207)	722 (170)	3111 (507)
Scenario 2	724 (214)	745 (175)	2974 (485)
Scenario 3	0 (0)	762 (179)	3196 (521)
Scenario 4	744 (219)	1590 (374)	1865 (304)
Scenario 5	757 (223)	779 (183)	1899 (309)
Scenario 6	0 (0)	803 (189)	1957 (319)

Note: The data in parentheses mean DMI (kg DM/head per year)
Source: DM content were collected from Feedipedia

Table 30(c). Feed costs in scenarios for AM, RF, and RM in mixed systems from beef buffalo (USD/year)

	Grain silage	Maize silage	Fodder beet	Total costs
Price (USD/kg)	0.25	0.19 (0.47)	(0.64)	-
2010	196	157	1271	1625
Scenario 1	174	139	1991	2305
Scenario 2	180	144	1903	2227
Scenario 3	0	147	2046	2193
Scenario 4	185	523	1194	1901
Scenario 5	188	150	1215	1554
Scenario 6	0	155	1252	1408

Note: The data in parentheses are the import prices and the others are the domestic prices. Domestic prices are reported as producer prices in 2008 while import prices are reported as CIF. CIF includes costs, insurance, and freight. Import prices are the average prices from all import countries in 2010. The price of sugar beet is based on the import price in 2012.
Source: Prices were collected from FAOSTAT

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(37.1%), 3 (35.0%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and Scenario 6 would reduce feed costs by 13.4%.

Figure 18 enteric emissions and feed costs per head in 2010. In terms of the mitigation potential, Scenario 1 would be the best choice as it could reduce enteric emissions by 13.6%, followed by Scenarios 2 (11.8%), 3 (8.8%), 4 (7.4%), 5 (6.0%), and 6 (1.7%). In terms of feed costs, costs would increase by 41.9% in Scenario 1, followed by Scenarios 2 (37.1%), 3 (35.0%), and 4 (17.0%). Scenario 5 would reduce feed costs by 4.4% and Scenario 6 would reduce feed costs by 13.4%.

Combining the mitigation potential and feed costs of alternative rations, Scenario 6 presents the best choice (0.9 USD/kg CO_2-eq), followed by Scenarios 5 (1.0), 4 (1.3), 3 (1.5), 2 (1.6), and 1 (1.6).

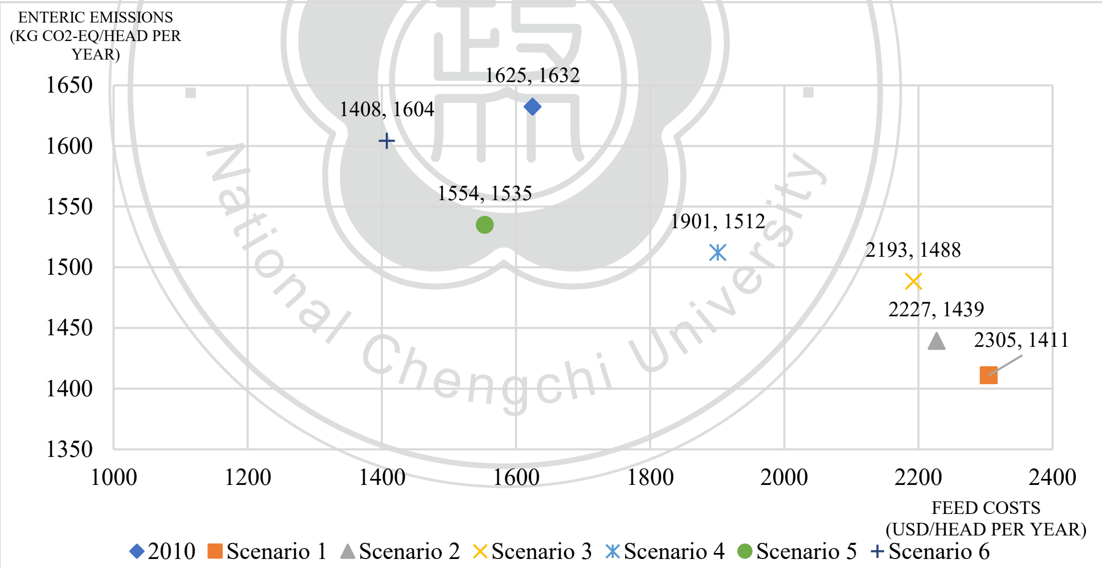

Figure 18: Enteric emissions and feed costs per head in 2010 for AM, RF, and RM in mixed systems from beef buffalo

Source: Calculated and collected from GLEAM-i and FAOSTAT

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6.5 Differences between cohorts, systems, herds, and bovines

No matter the scenario, enteric emissions for different groups are based on net energy requirements. Section 6.5 shows the different enteric emissions and feed costs of different groups in Scenario 1. Part 1 shows differences between cohorts. Part 2 shows differences between systems. Part 3 shows differences between dairy and beef herds. Part 4 shows differences between cattle and buffalo.

Tables 31(a) and 31(b) show live weights of different groups of cattle and buffalo. The four parts are all based on Figures 19 and 20, and Tables 32(a) and (b). Figure 19 shows the enteric emissions and feed costs per head for different categories of Scenario 1 in 2010. Figure 20 shows the total enteric emissions and feed costs for Scenario 1 in 2010. Tables 32(a) and (b) show the GEtot, DMI, enteric emissions, and feed costs for cattle and buffalo for Scenario 1 in 2010. Tables B1–B10 in Appendix B show the GEtot, DMI, enteric emissions, and feed costs for cattle and buffalo from Scenarios 2–6 in 2010.

6.5.1 Differences between AF and AM, RF, and RM

Enteric emissions per head (kg CO_2 -eq/year) for AF were higher than AM and replacement animals.

The coefficient of net energy requirement (MJ/kg^0.75 per day) for maintenance was higher in AF (AF: 0.386; RF:0.322; AM and RM:0.370). In other words, AF would require more net energy for maintenance. An increase of net energy requirement for maintenance would increase net energy requirements for activity and pregnancy. In our research, net energy requirement for milk production was only for AF, and for work were only for AM. Net energy requirement for growth was only for replacement animals.

Energy requirements for maintenance, activity, pregnancy, and milk production

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were greater than that for work and growth. Therefore, gross energy requirements (MJ/year) for AF were greater than AM and replacement animals. Gross energy contents of the rations were about 0.018 (MJ/kg DM) for different categories of cattle and buffalo. Therefore, gross energy requirements determined the DMI. Higher gross energy requirements for both cattle and buffalo caused DMI increase, which caused enteric emissions and feed costs per head increase.

Populations of AM, RF, and RM cattle in mixed systems were 1.4 times higher than AF. Due to 2010 populations, the total enteric emissions for AM, RF, and RM were 1.1–1.2 times higher than AF. Populations of AM, RF, and RM beef buffalo were 1.7 times higher than dairy buffalo (both in grassland systems and mixed systems). Due to 2010 populations, enteric emissions caused by AM, RF, and RM were 1.3 times higher than AF beef buffalo (both in grassland systems and mixed systems).

6.5.2 Differences between systems

Enteric emissions per head (kg CO_2 -eq/year) of cattle in mixed system were higher than grassland systems in 2010, except for AF dairy cattle (grassland systems: 1873; mixed systems: 1828). For buffalo, enteric emissions per head in mixed systems were lower than grassland systems.

The heavier weight of cattle caused enteric emissions in mixed systems to be higher than grassland systems, except for AF dairy cattle. A heavier weight causes more net energy requirements for maintenance, work, and growth. For AF dairy cattle, enteric emissions in mixed systems was lower than grassland systems due to lower energy requirement for activity. In mixed systems, 17% of net energy requirement for maintenance were used for activity. In grassland systems, 36% of net energy requirement for maintenance were used for activity. Cattle require more energy to move around in grassland systems. Gross energy requirement (MJ/year) of AF dairy cattle in

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mixed systems was lower than grassland systems (grassland system: 47.1; mixed system: 47.0). For buffalo, net energy requirement for activity caused enteric emissions in mixed systems to be lower than that in grassland systems. Therefore, gross energy requirement (MJ/year) was higher in grassland systems. Higher gross energy requirements in both cattle and buffalo cause DMI increases. An increase in DMI causes enteric emissions and feed costs per head increase.

The populations of cattle in mixed systems were 4–6 times higher than grassland systems. Due to cattle 2010 populations, enteric emissions in mixed systems were 4–8 times higher than grassland systems. Populations of buffalo in mixed systems were 9 times greater than in grassland systems. Due to larger populations, enteric emissions caused by buffalo in mixed systems were 8 times higher than grassland systems.

6.5.3 Differences between dairy and beef herds

Enteric emissions per head (kg CO_2-eq/year) for dairy bovine were higher than beef bovine, except for AF and replacement animals for buffalo in both grassland systems (dairy: 1407; beef: 1521) and mixed systems (dairy: 1316; beef: 1411).

Net energy requirements for milk production in dairy bovine were higher than beef bovine because beef bovine does not produce milk. Therefore, the gross energy requirements (MJ/year) of dairy bovine were greater than beef bovine, except for AF and replacement animals for beef buffalo in both grassland systems (dairy: 35; beef: 38) and mixed systems (cattle:33; buffalo: 35). Higher gross energy requirements in both cattle and buffalo caused DMI increases, which caused enteric emissions and feed costs per head to increase.

In groups of AM, RF, and RM dairy buffalo in both grassland and mixed systems, populations were 1.8 times higher than beef buffalo. Therefore, enteric emissions in dairy buffalo were 1.5 times higher than beef buffalo. In groups of AM, RF, and RM

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bovine in grassland systems, emissions per head for beef and dairy cattle were the same. Populations of beef cattle were 1.2 times higher than dairy cattle. Therefore, enteric emissions caused by beef cattle in 2010 were 1.2 times higher than dairy cattle.

6.5.4 Differences between cattle and buffalo

Enteric emissions per head (kg CO_2 -eq/year) in cattle were smaller than buffalo, except for AM and replacement animals for dairy buffalo in mixed systems (cattle: 1342; buffalo: 1316).

Net energy requirements (MJ/day) for cattle milk production were smaller than that of buffalo (cattle: 10.8; buffalo: 19.8). In addition, the live weights of buffalo were heavier than cattle, except for AM in mixed systems (cattle: 505kg; buffalo: 500kg). A heavier weight requires more net energy for maintenance. Therefore, cattle's gross energy requirements (MJ/year) were smaller than buffalo, except for AM and replacement animals of dairy buffalo in mixed systems (cattle: 33.5; buffalo: 32.8). A heavier weight for AM dairy buffalo in mixed systems required more net energy requirement for work. Higher gross energy requirements in both cattle and buffalo caused DMI increases, which caused enteric emissions and feed costs per head to increase.

Total enteric emissions for cattle were higher than buffalo in 2010 due to differing population sizes, except for AF dairy cattle in mixed systems. Though populations of AF dairy cattle in mixed systems were 1.1 times higher than dairy buffalo, enteric emissions were still lower due to enteric emissions per head (cattle: 2017; buffalo: 2767 kg CO_2 -eq/head per year).

In groups of AF and AM, RF, and RM bovine, populations of dairy cattle in grassland systems were 1.9–2.0 times higher than dairy buffalo in grassland systems. Therefore, enteric emissions by dairy cattle were 1.3–1.5 times higher than dairy

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buffalo in 2010. In groups of AM, RF, and RM bovine in mixed systems, dairy cattle populations were 1.4 times higher than that of dairy buffalo. In 2010, enteric emissions for dairy cattle were 1.4 times higher than dairy buffalo.

In groups of AF and AM, RF, RM bovine, beef cattle populations in grassland systems were 4–6 times higher than beef buffalo in grassland systems. Enteric emissions caused by beef cattle were 3–5 times higher than beef buffalo. In groups of AF and AM, RF, and RM bovine, populations of beef cattle in mixed systems were 2.5–3 times higher than beef buffalo in mixed systems. Enteric emissions caused by dairy cattle in mixed systems in 2010 were 2.4–2.5 times higher than beef buffalo (both from groups of AF and AM, RF, and RM cattle).

Table 31(a). Live weight of cattle in India in 2010 (kg)

	Dairy cattle		Beef cattle	
	Grassland	Mixed	Grassland	Mixed
AF	279	350	279	350
AM	363	505	363	505
RF	149	186.5	149	186.5
RM	191	264	191	264

Source: Collected from GLEAM-i

Table 31(b). Live weight of buffalo in India in 2010 (kg)

	Dairy buffalo		Beef buffalo	
	Grassland	Mixed	Grassland	Mixed
AF	478	478	478	478
AM	500	500	500	500
RF	255	255	255	255
RM	266	266	266	266

Source: Collected from GLEAM-i

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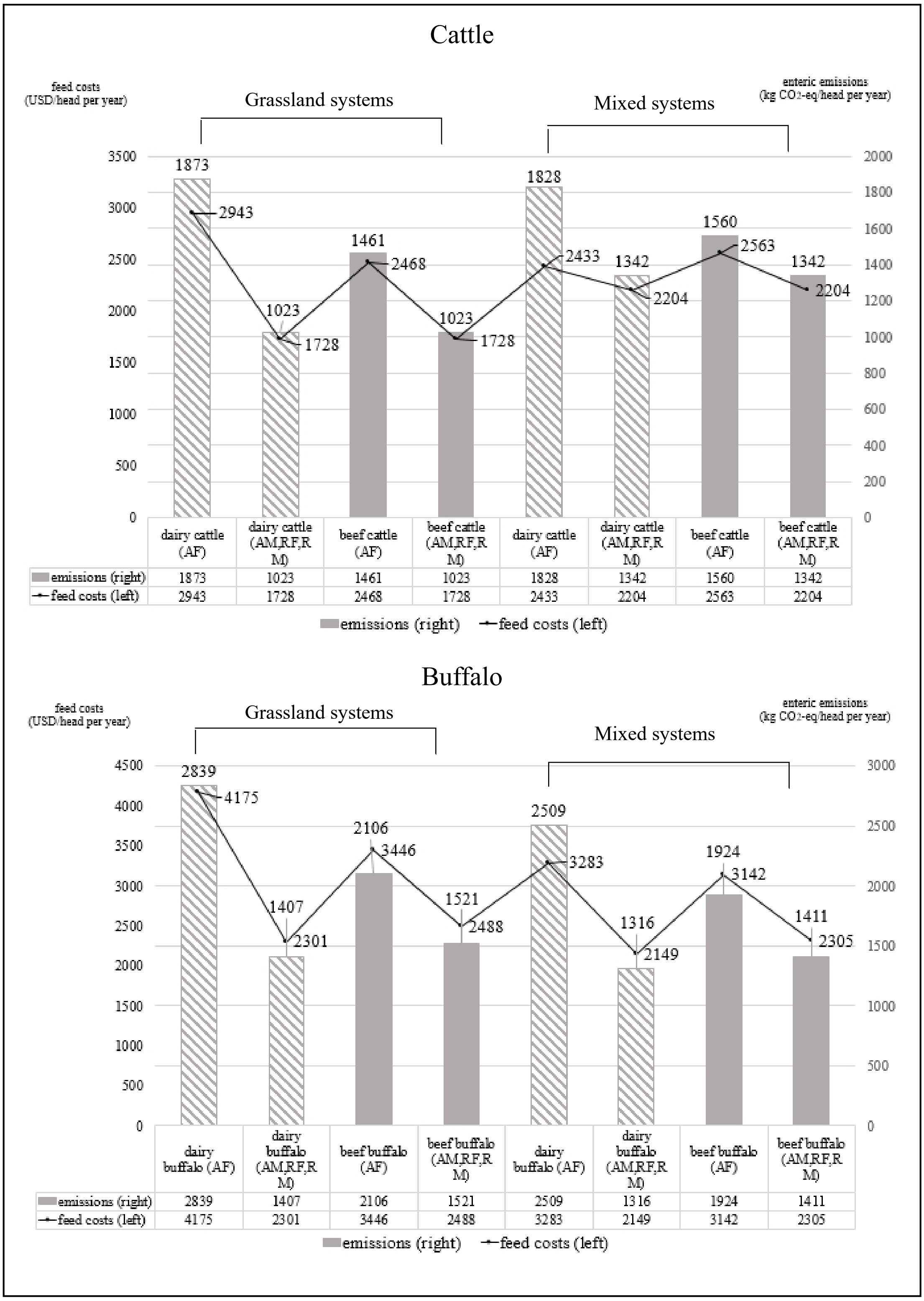

Figure 19: Enteric emissions and feed costs per head based on Scenario 1
Source: Enteric emissions were collected from GLEAM-i. Feed costs were calculated from GLEAM-i and FAOSTAT

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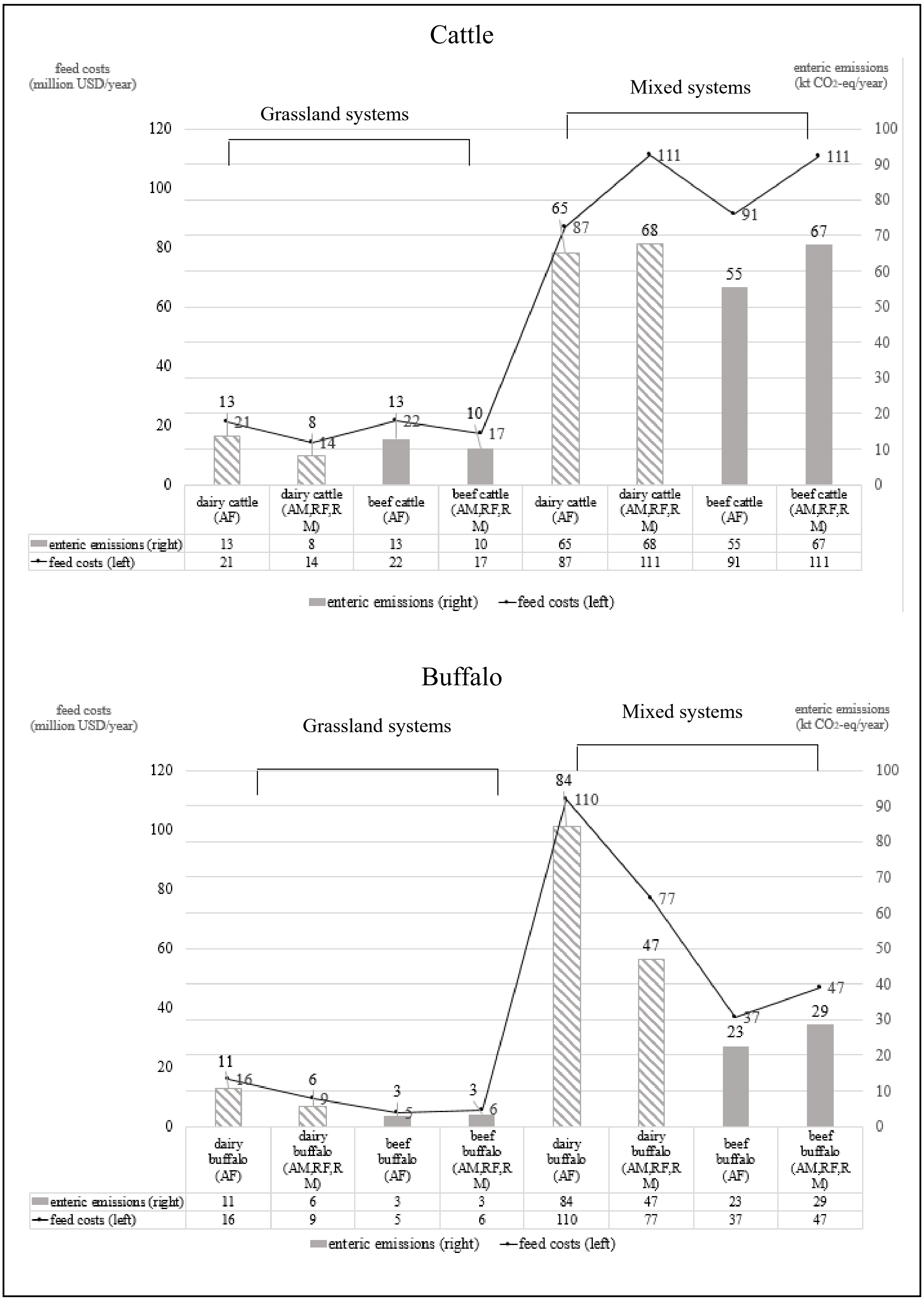

Figure 20: Enteric emissions and feed costs in 2010 based on Scenario 1

Source: Enteric emissions were collected from GLEAM-i. Feed costs were calculated from GLEAM-i and FAOSTAT

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Table 32(a). Enteric emissions and feed costs for cattle in Scenario 1 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	47.1	25.5	47.0	33.5	36.4	25.5	38.9	33.5
Total DM intake	kg DM/head per year	2,665	1,437	2,644	1,891	2,052	1,437	2,199	1,891
Enteric emissions	kg CO_2-eq/head per year	1,873	1,023	1,828	1,342	1,461	1,023	1,560	1,342
Feed costs	USD/head per year	2,943	1,728	2,433	2,204	2,468	1,728	2,563	2,204
Total populations in 2010									
GEtot	million MJ/year	339	208	1672	1685	318	253	1383	1682
Total intake	kt DM/year	19,182	11,719	94,162	95,186	17,977	14,262	78,165	95,017
Enteric emissions	kt CO_2-eq/year	13,482	8,342	65,106	67,536	12,797	10,152	55,460	67,416
Feed costs	million USD/year	21,182	14,092	86,650	110,950	21,617	17,149	91,111	110,754
Costs per unit	USD/kg CO_2-eq	1.6	1.7	1.3	1.6	1.7	1.7	1.6	1.6

Source: Feed costs were calculated from FAOSTAT. Other information was calculated and collected from GLEAM-i

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Table 32(b). Enteric emissions and feed costs for buffalo in Scenario 1 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	71.9	35.2	64.5	32.8	52.6	38.0	48.0	35.2
Total DM intake	kg DM/head per year	4,003	1,974	3,568	1,844	2,956	2,134	2,696	1,977
Enteric emissions	kg CO_2-eq/head per year	2,839	1,407	2,509	1,316	2,106	1,521	1,924	1,411
Feed costs	USD/head per year	4,175	2,301	3,283	2,149	3,446	2,488	3,142	2,305
Total populations in 2010									
GEtot	million MJ/year	272	141	2,169	1,175	70	86	564	712
Total intake	kt DM/year	15,131	7,942	119,925	65,968	3,907	4,853	31,684	39,981
Enteric emissions	kt CO_2-eq/year	10,731	5,659	84,337	47,074	2,784	3,458	22,609	28,530
Feed costs	million USD/year	15,780	9,257	110,358	76,894	4,554	5,656	36,931	46,602
Costs per unit	USD/kg CO_2-eq	1.5	1.6	1.3	1.6	1.6	1.6	1.6	1.6

Source: Feed costs were calculated from FAOSTAT. Other information was calculated and collected from GLEAM-i

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7 Conclusions

India was the largest emitter of enteric emissions in the world in 2017 at 290 million t CO_2-eq of enteric emissions (14% of global enteric emissions) (FAOSTAT, 2019). Indian cattle and buffalo accounted for 93% of enteric emissions in India in 2016 (FAOSTAT, 2019). Dietary manipulation is a feasible and low-cost way of reducing enteric emissions (O'Mara et al., 1998; Martin, Morgavi, & Doreau, 2009). The purpose of this study was to find alternative rations to help the Indian cattle and buffalo sectors reduce enteric methane emissions. We suggested a practical and low-cost method in which the composition of rations used in 2010 is adjusted to attain emissions reductions. We used the GLEAM-i model to calculate enteric emissions, which is based on the IPCC Tier 2 approach.

In our research design, we considered 12 feed materials of roughage. Two feed materials of roughage were paired in a group for substitution. In a group, one feed material replaced the other feed material, with the former being called the alternative feed material, and the latter being the replaced feed material. The percentage change was based on the percentage of DMI change as a result of the replaced feed material. After changing the percentage of feed materials, rations did not contain replaced feed material. The percentages of other feed materials were unchanged.

We assumed feed consumption in 2010 to be the supply ceiling in our Scenarios. If feed intake in a Scenario exceeded 2010 levels, additional feed materials were assumed to be imported. We assumed that imports of grass and hay were unlimited and free of charge. Import supplies of crop residues are uncertain as it depends on the amount of crop residues left after harvest. Therefore, we assumed that no crop residues were imported to India. This assumption results in two limits of our research. First, crop residues cannot replace any feed materials. Second, total DMI in every Scenario must

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be smaller than that of 2010. In our research design, emissions factors (kg CO_2-eq/kg DM) due to alternative feed materials should be relatively smaller than replaced feed materials.

In our research, we considered 37 new and feasible feeding methods. After comparing methane emissions and feed costs of these 37 methods, we excluded relatively poor results. We proposed six Scenarios of alternative rations that were aimed at reducing enteric emissions. Among the six Scenarios, feed materials of a higher digestibility were increased to replace materials of lower digestibility. Combining the mitigation potentials and feed costs of alternative rations, Scenario 6 would be the best choice, followed by Scenarios 5, 4, 3, 2, and 1. In the short run, Scenario 6 would be the best choice for India to cut enteric emissions without adding significant financial burden; in addition, it could reduce enteric emissions by 2% (8.7 million t CO_2-eq/year) and reduce feed costs by 13% (71.7 billion USD/year). Relatively more costly scenarios of 1–5 could be feasible when India grows to have a better economic viability.

The growing potential of the Indian economy will increase the domestic consumption of meat and dairy products. The population of India was 1.3 billion in 2018, which accounted for 18% of the global population (FAOSTAT, 2020). The United Nations predicts that the population of India will increase to 1.5 billion by 2030. India will become the most populous country in the world by 2030. The growing population and the Indian economy will increase its livestock emissions of GHG. Therefore, the mitigation of livestock GHG emissions in India is an important issue for the global climate system.

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Appendix A

Table A1. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of dairy cattle in grassland systems)

AM, RF, RM of dairy cattle in grassland systems				
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-14.1	41.0
	7	Sugarcane crop residues	-12.8	52.6
	11	Wheat crop residues	-12.3	36.5
	3	Grain silage	-9.2	34.5
	10	Grain crop residues	-7.7	22.0
	5	Hay	-6.5	25.5
	6	Maize crop residues	-5.6	25.6
	9	Sorghum crop residues	-5.5	18.1
	4	Maize silage	-5.0	32.7
	8	Millet crop residues	-3.9	13.2
	2	Fresh grass	-3.0	18.6
Fresh grass	19	Wheat crop residues	-6.2	-4.6
	15	Sugarcane crop residues	-4.4	-3.3
	18	Grain crop residues	-3.9	-3.0
	17	Sorghum crop residues	-2.3	-1.8
	13	Hay	-2.2	-1.8
	12	Grain silage	-1.8	-13.4
	16	Millet crop residues	-1.6	-1.3
	14	Maize crop residues	-1.4	-1.0
Grain silage	26	Wheat crop residues	-4.8	7.2
	25	Grain crop residues	-3.0	4.1
	22	Sugarcane crop residues	-2.3	13.1
	24	Sorghum crop residues	-1.6	3.8
	20	Hay	-1.2	6.0
	23	Millet crop residues	-1.0	2.8
	21	Maize crop residues	-0.4	6.6
Maize silage	33	Wheat crop residues	-7.7	16.6
	29	Sugarcane crop residues	-6.4	26.3
	32	Grain crop residues	-4.8	9.8
	27	Hay	-3.2	12.4
	31	Sorghum crop residues	-3.1	8.5
	28	Maize crop residues	-2.4	12.9
	30	Millet crop residues	-2.1	6.2
Hay	37	Wheat crop residues	-3.0	-2.0
	36	Grain crop residues	-2.0	-1.4
	35	Sorghum crop residues	-0.8	-0.5
	34	Millet crop residues	-0.4	-0.3

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A2. Percentage change in methane emissions and feed costs in 2010 (AF of dairy cattle in mixed systems)

AF of dairy cattle in mixed systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-9.3	48.2	Grain silage	26	Wheat crop residues	-3.0	8.8
	7	Sugarcane crop residues	-8.5	59.0		25	Grain crop residues	-1.9	5.1
	11	Wheat crop residues	-8.1	41.9		22	Sugarcane crop residues	-1.5	13.9
	3	Grain silage	-6.0	38.5		24	Sorghum crop residues	-1.0	4.3
	10	Grain crop residues	-5.0	25.1		20	Hay	-1.0	8.5
	5	Hay	-5.5	37.2		23	Millet crop residues	-0.7	3.1
	6	Maize crop residues	-3.6	27.8		21	Maize crop residues	-0.2	6.7
	9	Sorghum crop residues	-3.5	20.2	Maize silage	33	Wheat crop residues	-5.0	20.1
	4	Maize silage	-3.2	34.5		29	Sugarcane crop residues	-4.1	29.6
	8	Millet crop residues	-2.5	14.6		32	Grain crop residues	-3.1	11.9
	2	Fresh grass	-1.0	9.9		27	Hay	-2.7	18.5
Fresh grass	19	Wheat crop residues	-4.0	-2.7		31	Sorghum crop residues	-1.9	9.8
	15	Sugarcane crop residues	-2.8	-1.9		28	Maize crop residues	-1.5	14.0
	18	Grain crop residues	-2.5	-1.7		30	Millet crop residues	-1.3	7.1
	17	Sorghum crop residues	-1.5	-1.0	Hay	37	Wheat crop residues	-1.9	-1.1
	13	Hay	-1.8	-1.4		36	Grain crop residues	-1.2	-0.8
	12	Grain silage	-1.1	-12.9		35	Sorghum crop residues	-0.5	-0.3
	16	Millet crop residues	-1.0	-0.7		34	Millet crop residues	-0.3	-0.2
	14	Maize crop residues	-0.9	-0.6					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A3. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of dairy cattle in mixed systems)

Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
AM, RF, and RM of dairy cattle in mixed systems				
Fodder beet	1	Rice crop residues	-13.6	41.8
	7	Sugarcane crop residues	-12.4	53.3
	11	Wheat crop residues	-11.9	37.0
	3	Grain silage	-8.9	34.9
	10	Grain crop residues	-7.5	22.3
	5	Hay	-8.2	33.9
	6	Maize crop residues	-5.4	25.8
	9	Sorghum crop residues	-5.3	18.4
	4	Maize silage	-4.8	32.9
	8	Millet crop residues	-3.7	13.4
	2	Fresh grass	-1.5	9.5
Fresh grass	19	Wheat crop residues	-6.0	-4.4
	15	Sugarcane crop residues	-4.2	-3.2
	18	Grain crop residues	-3.8	-2.8
	17	Sorghum crop residues	-2.2	-1.7
	13	Hay	-2.8	-2.2
	12	Grain silage	-1.7	-13.4
	16	Millet crop residues	-1.5	-1.2
	14	Maize crop residues	-1.3	-1.0
Grain silage	26	Wheat crop residues	-4.6	7.3
	25	Grain crop residues	-2.9	4.2
	22	Sugarcane crop residues	-2.2	13.2
	24	Sorghum crop residues	-1.6	3.9
	20	Hay	-1.5	8.0
	23	Millet crop residues	-1.0	2.8
	21	Maize crop residues	-0.4	6.6
Maize silage	33	Wheat crop residues	-7.4	17.0
	29	Sugarcane crop residues	-6.2	26.6
	32	Grain crop residues	-4.6	10.0
	27	Hay	-4.1	16.6
	31	Sorghum crop residues	-2.9	8.6
	28	Maize crop residues	-2.3	13.1
	30	Millet crop residues	-2.0	6.3
Hay	37	Wheat crop residues	-2.9	-1.9
	36	Grain crop residues	-1.9	-1.3
	35	Sorghum crop residues	-0.7	-0.5
	34	Millet crop residues	-0.4	-0.3

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A4. Percentage change in methane emissions and feed costs in 2010 (AF of beef cattle in grassland systems)

AF of beef cattle in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.1	42.8	Grain silage	26	Wheat crop residues	-4.4	7.6
	7	Sugarcane crop residues	-11.9	54.3		25	Grain crop residues	-2.8	4.4
	11	Wheat crop residues	-11.4	37.9		22	Sugarcane crop residues	-2.1	13.4
	3	Grain silage	-8.5	35.6		24	Sorghum crop residues	-1.5	4.0
	10	Grain crop residues	-7.1	22.9		20	Hay	-1.1	6.1
	5	Hay	-5.9	26.3		23	Millet crop residues	-0.9	2.9
	6	Maize crop residues	-5.1	26.2		21	Maize crop residues	-0.4	6.6
	9	Sorghum crop residues	-5.0	18.7	Maize silage	33	Wheat crop residues	-7.1	17.5
	4	Maize silage	-4.5	33.3		29	Sugarcane crop residues	-5.9	27.1
	8	Millet crop residues	-3.5	13.6		32	Grain crop residues	-4.4	10.3
	2	Fresh grass	-2.7	19.0		27	Hay	-2.9	12.8
Fresh grass	19	Wheat crop residues	-5.7	-4.1		31	Sorghum crop residues	-2.8	8.8
	15	Sugarcane crop residues	-4.0	-3.0		28	Maize crop residues	-2.2	13.2
	18	Grain crop residues	-3.6	-2.6		30	Millet crop residues	-1.9	6.4
	17	Sorghum crop residues	-2.1	-1.6	Hay	37	Wheat crop residues	-2.7	-1.7
	13	Hay	-2.0	-1.6		36	Grain crop residues	-1.8	-1.2
	12	Grain silage	-1.6	-13.3		35	Sorghum crop residues	-0.7	-0.5
	16	Millet crop residues	-1.4	-1.1		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.3	-0.9					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A5. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of beef cattle in grassland systems)

AM, RF, and RM of beef cattle in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-14.1	41.0	Grain silage	26	Wheat crop residues	-4.8	7.2
	7	Sugarcane crop residues	-12.8	52.6		25	Grain crop residues	-3.0	4.1
	11	Wheat crop residues	-12.3	36.5		22	Sugarcane crop residues	-2.3	13.1
	3	Grain silage	-9.2	34.5		24	Sorghum crop residues	-1.6	3.8
	10	Grain crop residues	-7.7	22.0		20	Hay	-1.2	6.0
	5	Hay	-6.5	25.5		23	Millet crop residues	-1.0	2.8
	6	Maize crop residues	-5.6	25.6		21	Maize crop residues	-0.4	6.6
	9	Sorghum crop residues	-5.5	18.1	Maize silage	33	Wheat crop residues	-7.7	16.6
	4	Maize silage	-5.0	32.7		29	Sugarcane crop residues	-6.4	26.3
	8	Millet crop residues	-3.9	13.2		32	Grain crop residues	-4.8	9.8
	2	Fresh grass	-3.0	18.6		27	Hay	-3.2	12.4
Fresh grass	19	Wheat crop residues	-6.2	-4.6		31	Sorghum crop residues	-3.1	8.5
	15	Sugarcane crop residues	-4.4	-3.3		28	Maize crop residues	-2.4	12.9
	18	Grain crop residues	-3.9	-3.0		30	Millet crop residues	-2.1	6.2
	17	Sorghum crop residues	-2.3	-1.8	Hay	37	Wheat crop residues	-3.0	-2.0
	13	Hay	-2.2	-1.8		36	Grain crop residues	-2.0	-1.4
	12	Grain silage	-1.8	-13.4		35	Sorghum crop residues	-0.8	-0.5
	16	Millet crop residues	-1.6	-1.3		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.4	-1.0					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A6. Percentage change in methane emissions and feed costs in 2010 (AF of beef cattle in mixed systems)

AF of beef cattle in mixed systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-12.6	43.4	Grain silage	26	Wheat crop residues	-4.2	7.8
	7	Sugarcane crop residues	-11.4	54.9		25	Grain crop residues	-2.6	4.4
	11	Wheat crop residues	-11.0	38.4		22	Sugarcane crop residues	-2.0	13.4
	3	Grain silage	-8.1	36.0		24	Sorghum crop residues	-1.4	4.0
	10	Grain crop residues	-6.8	23.1		20	Hay	-1.4	8.2
	5	Hay	-7.5	34.9		23	Millet crop residues	-0.9	2.9
	6	Maize crop residues	-4.9	26.4		21	Maize crop residues	-0.3	6.6
	9	Sorghum crop residues	-4.8	18.9	Maize silage	33	Wheat crop residues	-6.8	17.8
	4	Maize silage	-4.4	33.4		29	Sugarcane crop residues	-5.7	27.4
	8	Millet crop residues	-3.4	13.7		32	Grain crop residues	-4.2	10.5
	2	Fresh grass	-1.3	9.6		27	Hay	-3.7	17.1
Fresh grass	19	Wheat crop residues	-5.5	-3.9		31	Sorghum crop residues	-2.7	8.9
	15	Sugarcane crop residues	-3.9	-2.8		28	Maize crop residues	-2.1	13.3
	18	Grain crop residues	-3.4	-2.5		30	Millet crop residues	-1.8	6.5
	17	Sorghum crop residues	-2.1	-1.5	Hay	37	Wheat crop residues	-2.6	-1.7
	13	Hay	-2.6	-2.0		36	Grain crop residues	-1.7	-1.2
	12	Grain silage	-1.6	-13.2		35	Sorghum crop residues	-0.7	-0.4
	16	Millet crop residues	-1.4	-1.1		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.2	-0.9					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A7. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of beef cattle in mixed systems)

AM, RF, and RM of beef cattle in mixed systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.6	41.8	Grain silage	26	Wheat crop residues	-4.6	7.3
	7	Sugarcane crop residues	-12.4	53.3		25	Grain crop residues	-2.9	4.2
	11	Wheat crop residues	-11.9	37.0		22	Sugarcane crop residues	-2.2	13.2
	3	Grain silage	-8.9	34.9		24	Sorghum crop residues	-1.6	3.9
	10	Grain crop residues	-7.5	22.3		20	Hay	-1.5	8.0
	5	Hay	-8.2	33.9		23	Millet crop residues	-1.0	2.8
	6	Maize crop residues	-5.4	25.8		21	Maize crop residues	-0.4	6.6
	9	Sorghum crop residues	-5.3	18.4	Maize silage	33	Wheat crop residues	-7.4	17.0
	4	Maize silage	-4.8	32.9		29	Sugarcane crop residues	-6.2	26.6
	8	Millet crop residues	-3.7	13.4		32	Grain crop residues	-4.6	10.0
	2	Fresh grass	-1.5	9.5		27	Hay	-4.1	16.6
Fresh grass	19	Wheat crop residues	-6.0	-4.4		31	Sorghum crop residues	-2.9	8.6
	15	Sugarcane crop residues	-4.2	-3.2		28	Maize crop residues	-2.3	13.1
	18	Grain crop residues	-3.8	-2.8		30	Millet crop residues	-2.0	6.3
	17	Sorghum crop residues	-2.2	-1.7	Hay	37	Wheat crop residues	-2.9	-1.9
	13	Hay	-2.8	-2.2		36	Grain crop residues	-1.9	-1.3
	12	Grain silage	-1.7	-13.4		35	Sorghum crop residues	-0.7	-0.5
	16	Millet crop residues	-1.5	-1.2		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.3	-1.0					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A8. Percentage change in methane emissions and feed costs in 2010 (AF of dairy buffalo in grassland systems)

Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-10.9	45.9	Grain silage	26	Wheat crop residues	-3.6	8.3
Fodder beet	7	Sugarcane crop residues	-9.9	57.1	Grain silage	25	Grain crop residues	-2.3	4.8
Fodder beet	11	Wheat crop residues	-9.5	40.3	Grain silage	22	Sugarcane crop residues	-1.7	13.7
Fodder beet	3	Grain silage	-7.0	37.3	Grain silage	24	Sorghum crop residues	-1.2	4.2
Fodder beet	10	Grain crop residues	-5.9	24.2	Grain silage	20	Hay	-0.9	6.3
Fodder beet	5	Hay	-4.9	27.4	Grain silage	23	Millet crop residues	-0.8	3.0
Fodder beet	6	Maize crop residues	-4.2	27.2	Grain silage	21	Maize crop residues	-0.3	6.6
Fodder beet	9	Sorghum crop residues	-4.1	19.6	Maize silage	33	Wheat crop residues	-5.8	19.0
Fodder beet	4	Maize silage	-3.7	34.0	Maize silage	29	Sugarcane crop residues	-4.9	28.6
Fodder beet	8	Millet crop residues	-2.9	14.2	Maize silage	32	Grain crop residues	-3.6	11.3
Fodder beet	2	Fresh grass	-2.2	19.4	Maize silage	27	Hay	-2.4	13.5
Fresh grass	19	Wheat crop residues	-4.7	-3.2	Maize silage	31	Sorghum crop residues	-2.3	9.4
Fresh grass	15	Sugarcane crop residues	-3.3	-2.4	Maize silage	28	Maize crop residues	-1.8	13.7
Fresh grass	18	Grain crop residues	-2.9	-2.1	Maize silage	30	Millet crop residues	-1.6	6.8
Fresh grass	17	Sorghum crop residues	-1.7	-1.3	Hay	37	Wheat crop residues	-2.2	-1.4
Fresh grass	13	Hay	-1.6	-1.2	Hay	36	Grain crop residues	-1.5	-1.0
Fresh grass	12	Grain silage	-1.3	-13.0	Hay	35	Sorghum crop residues	-0.6	-0.4
Fresh grass	16	Millet crop residues	-1.2	-0.9	Hay	34	Millet crop residues	-0.3	-0.2
Fresh grass	14	Maize crop residues	-1.0	-0.7					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A9. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of dairy buffalo in grassland systems)

AM, RF, and RM from dairy buffalo in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.7	41.6	Grain silage	26	Wheat crop residues	-4.6	7.3
	7	Sugarcane crop residues	-12.5	53.1		25	Grain crop residues	-2.9	4.1
	11	Wheat crop residues	-12.0	36.8		22	Sugarcane crop residues	-2.2	13.2
	3	Grain silage	-8.9	34.8		24	Sorghum crop residues	-1.6	3.8
	10	Grain crop residues	-7.5	22.2		20	Hay	-1.2	6.0
	5	Hay	-6.3	25.7		23	Millet crop residues	-1.0	2.8
	6	Maize crop residues	-5.4	25.8		21	Maize crop residues	-0.4	6.6
	9	Sorghum crop residues	-5.3	18.3	Maize silage	33	Wheat crop residues	-7.5	16.9
	4	Maize silage	-4.8	32.8		29	Sugarcane crop residues	-6.3	26.5
	8	Millet crop residues	-3.8	13.3		32	Grain crop residues	-4.7	10.0
	2	Fresh grass	-2.9	18.7		27	Hay	-3.1	12.6
Fresh grass	19	Wheat crop residues	-6.1	-4.5		31	Sorghum crop residues	-3.0	8.6
	15	Sugarcane crop residues	-4.3	-3.2		28	Maize crop residues	-2.3	13.0
	18	Grain crop residues	-3.8	-2.9		30	Millet crop residues	-2.0	6.2
	17	Sorghum crop residues	-2.3	-1.7	Hay	37	Wheat crop residues	-2.9	-1.9
	13	Hay	-2.1	-1.7		36	Grain crop residues	-1.9	-1.3
	12	Grain silage	-1.7	-13.4		35	Sorghum crop residues	-0.7	-0.5
	16	Millet crop residues	-1.5	-1.2		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.3	-1.0					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

.

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Table A10. Percentage change in methane emissions and feed costs in 2010 (AF of dairy buffalo in mixed systems)

AF of dairy buffalo in mixed systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-9.3	48.2	Grain silage	26	Wheat crop residues	-3.0	8.8
	7	Sugarcane crop residues	-8.4	59.0		25	Grain crop residues	-1.9	5.1
	11	Wheat crop residues	-8.1	41.9		22	Sugarcane crop residues	-1.5	13.9
	3	Grain silage	-5.9	38.5		24	Sorghum crop residues	-1.0	4.3
	10	Grain crop residues	-5.0	25.1		20	Hay	-1.0	8.5
	5	Hay	-5.5	37.2		23	Millet crop residues	-0.7	3.1
	6	Maize crop residues	-3.6	27.9		21	Maize crop residues	-0.2	6.7
	9	Sorghum crop residues	-3.5	20.2	Maize silage	33	Wheat crop residues	-4.9	20.1
	4	Maize silage	-3.2	34.5		29	Sugarcane crop residues	-4.1	29.6
	8	Millet crop residues	-2.4	14.6		32	Grain crop residues	-3.1	11.9
	2	Fresh grass	-1.0	9.9		27	Hay	-2.7	18.5
Fresh grass	19	Wheat crop residues	-4.0	-2.7		31	Sorghum crop residues	-1.9	9.8
	15	Sugarcane crop residues	-2.8	-1.9		28	Maize crop residues	-1.5	14.0
	18	Grain crop residues	-2.5	-1.7		30	Millet crop residues	-1.3	7.1
	17	Sorghum crop residues	-1.5	-1.0	Hay	37	Wheat crop residues	-1.9	-1.1
	13	Hay	-1.8	-1.4		36	Grain crop residues	-1.2	-0.8
	12	Grain silage	-1.1	-12.9		35	Sorghum crop residues	-0.5	-0.3
	16	Millet crop residues	-1.0	-0.7		34	Millet crop residues	-0.3	-0.2
	14	Maize crop residues	-0.9	-0.6					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A11. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of dairy buffalo in mixed systems)

AM, RF, and RM of dairy buffalo in mixed systems

Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.9	41.3
	7	Sugarcane crop residues	-12.6	52.8
	11	Wheat crop residues	-12.1	36.6
	3	Grain silage	-9.1	34.6
	10	Grain crop residues	-7.6	22.1
	5	Hay	-8.3	33.6
	6	Maize crop residues	-5.5	25.7
	9	Sorghum crop residues	-5.4	18.2
	4	Maize silage	-4.9	32.7
	8	Millet crop residues	-3.8	13.3
	2	Fresh grass	-1.5	9.4
Fresh grass	19	Wheat crop residues	-6.1	-4.5
	15	Sugarcane crop residues	-4.3	-3.3
	18	Grain crop residues	-3.9	-2.9
	17	Sorghum crop residues	-2.3	-1.8
	13	Hay	-2.9	-2.3
	12	Grain silage	-1.8	-13.4
	16	Millet crop residues	-1.5	-1.2
	14	Maize crop residues	-1.4	-1.0

Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Grain silage	26	Wheat crop residues	-4.7	7.2
	25	Grain crop residues	-3.0	4.1
	22	Sugarcane crop residues	-2.3	13.1
	24	Sorghum crop residues	-1.6	3.8
	20	Hay	-1.6	8.0
	23	Millet crop residues	-1.0	2.8
	21	Maize crop residues	-0.4	6.6
Maize silage	33	Wheat crop residues	-7.6	16.7
	29	Sugarcane crop residues	-6.3	26.4
	32	Grain crop residues	-4.7	9.9
	27	Hay	-4.2	16.5
	31	Sorghum crop residues	-3.0	8.5
	28	Maize crop residues	-2.3	13.0
	30	Millet crop residues	-2.1	6.2
Hay	37	Wheat crop residues	-3.0	-2.0
	36	Grain crop residues	-1.9	-1.4
	35	Sorghum crop residues	-0.7	-0.5
	34	Millet crop residues	-0.4	-0.3

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A12. Percentage change in methane emissions and feed costs in 2010 (AF of beef buffalo in grassland systems)

AF of beef buffalo in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-12.5	43.5	Grain silage	26	Wheat crop residues	-4.2	7.8
	7	Sugarcane crop residues	-11.4	55.0		25	Grain crop residues	-2.6	4.5
	11	Wheat crop residues	-10.9	38.5		22	Sugarcane crop residues	-2.0	13.4
	3	Grain silage	-8.1	36.0		24	Sorghum crop residues	-1.4	4.0
	10	Grain crop residues	-6.8	23.2		20	Hay	-1.0	6.1
	5	Hay	-5.7	26.5		23	Millet crop residues	-0.9	2.9
	6	Maize crop residues	-4.9	26.5		21	Maize crop residues	-0.3	6.6
	9	Sorghum crop residues	-4.8	18.9	Maize silage	33	Wheat crop residues	-6.8	17.9
	4	Maize silage	-4.3	33.5		29	Sugarcane crop residues	-5.7	27.5
	8	Millet crop residues	-3.4	13.8		32	Grain crop residues	-4.2	10.6
	2	Fresh grass	-2.6	19.1		27	Hay	-2.8	13.0
Fresh grass	19	Wheat crop residues	-5.5	-3.9		31	Sorghum crop residues	-2.7	8.9
	15	Sugarcane crop residues	-3.8	-2.8		28	Maize crop residues	-2.1	13.3
	18	Grain crop residues	-3.4	-2.5		30	Millet crop residues	-1.8	6.5
	17	Sorghum crop residues	-2.0	-1.5	Hay	37	Wheat crop residues	-2.6	-1.6
	13	Hay	-1.9	-1.5		36	Grain crop residues	-1.7	-1.2
	12	Grain silage	-1.6	-13.2		35	Sorghum crop residues	-0.7	-0.4
	16	Millet crop residues	-1.4	-1.1		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.2	-0.8					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

.

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Table A13. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of beef buffalo in grassland systems)

AM, RF, and RM of beef buffalo in grassland systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.4	42.1	Grain silage	26	Wheat crop residues	-4.5	7.4
	7	Sugarcane crop residues	-12.2	53.6		25	Grain crop residues	-2.9	4.2
	11	Wheat crop residues	-11.7	37.3		22	Sugarcane crop residues	-2.2	13.3
	3	Grain silage	-8.7	35.1		24	Sorghum crop residues	-1.5	3.9
	10	Grain crop residues	-7.3	22.5		20	Hay	-1.1	6.1
	5	Hay	-6.1	25.9		23	Millet crop residues	-1.0	2.8
	6	Maize crop residues	-5.3	26.0		21	Maize crop residues	-0.4	6.6
	9	Sorghum crop residues	-5.2	18.5	Maize silage	33	Wheat crop residues	-7.3	17.1
	4	Maize silage	-4.7	33.0		29	Sugarcane crop residues	-6.1	26.8
	8	Millet crop residues	-3.6	13.4		32	Grain crop residues	-4.6	10.1
	2	Fresh grass	-2.8	18.8		27	Hay	-3.0	12.7
Fresh grass	19	Wheat crop residues	-5.9	-4.3		31	Sorghum crop residues	-2.9	8.7
	15	Sugarcane crop residues	-4.2	-3.1		28	Maize crop residues	-2.2	13.1
	18	Grain crop residues	-3.7	-2.8		30	Millet crop residues	-2.0	6.3
	17	Sorghum crop residues	-2.2	-1.7	Hay	37	Wheat crop residues	-2.8	-1.9
	13	Hay	-2.1	-1.6		36	Grain crop residues	-1.8	-1.3
	12	Grain silage	-1.7	-13.3		35	Sorghum crop residues	-0.7	-0.5
	16	Millet crop residues	-1.5	-1.2		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.3	-0.9					

Source: enteric emissions were collected from GLEAM-i. Feed costs were calculated from GLEAM-i and FAOSTAT

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Table A14. Percentage change in methane emissions and feed costs in 2010 (AF of beef buffalo in mixed systems)

AF of beef buffalo in mixed systems									
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs	Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-12.6	43.5	Grain silage	26	Wheat crop residues	-4.2	7.8
	7	Sugarcane crop residues	-11.4	54.9		25	Grain crop residues	-2.6	4.4
	11	Wheat crop residues	-10.9	38.4		22	Sugarcane crop residues	-2.0	13.4
	3	Grain silage	-8.1	36.0		24	Sorghum crop residues	-1.4	4.0
	10	Grain crop residues	-6.8	23.1		20	Hay	-1.4	8.2
	5	Hay	-7.5	34.9		23	Millet crop residues	-0.9	2.9
	6	Maize crop residues	-4.9	26.4		21	Maize crop residues	-0.3	6.6
	9	Sorghum crop residues	-4.8	18.9	Maize silage	33	Wheat crop residues	-6.8	17.8
	4	Maize silage	-4.4	33.4		29	Sugarcane crop residues	-2.0	33.0
	8	Millet crop residues	-3.4	13.7		32	Grain crop residues	-4.2	10.5
	2	Fresh grass	-1.3	9.6		27	Hay	-3.7	17.1
Fresh grass	19	Wheat crop residues	-5.5	-3.9		31	Sorghum crop residues	-2.7	8.9
	15	Sugarcane crop residues	-3.9	-2.8		28	Maize crop residues	-2.1	13.3
	18	Grain crop residues	-3.4	-2.5		30	Millet crop residues	-1.8	6.5
	17	Sorghum crop residues	-2.0	-1.5	Hay	37	Wheat crop residues	-2.6	-1.7
	13	Hay	-2.6	-2.0		36	Grain crop residues	-1.7	-1.2
	12	Grain silage	-1.6	-13.2		35	Sorghum crop residues	-0.7	-0.4
	16	Millet crop residues	-1.4	-1.1		34	Millet crop residues	-0.4	-0.3
	14	Maize crop residues	-1.2	-0.9					

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Table A15. Percentage change in methane emissions and feed costs in 2010 (AM, RF, and RM of beef buffalo in mixed systems)

AM, RF, and RM of beef buffalo in mixed systems				
Alternative feed materials		Replaced feed materials	Methane emissions	Feed costs
Fodder beet	1	Rice crop residues	-13.6	41.9
	7	Sugarcane crop residues	-12.3	53.4
	11	Wheat crop residues	-11.8	37.1
	3	Grain silage	-8.8	35.0
	10	Grain crop residues	-7.4	22.4
	5	Hay	-8.1	34.0
	6	Maize crop residues	-5.3	25.9
	9	Sorghum crop residues	-5.2	18.4
	4	Maize silage	-4.7	32.9
	8	Millet crop residues	-3.7	13.4
	2	Fresh grass	-1.5	9.5
Fresh grass	19	Wheat crop residues	-6.0	-4.4
	15	Sugarcane crop residues	-4.2	-3.2
	18	Grain crop residues	-3.7	-2.8
	17	Sorghum crop residues	-2.2	-1.7
	13	Hay	-2.8	-2.2
	12	Grain silage	-1.7	-13.4
	16	Millet crop residues	-1.5	-1.2
	14	Maize crop residues	-1.3	-1.0
Grain silage	26	Wheat crop residues	-4.6	7.3
	25	Grain crop residues	-2.9	4.2
	22	Sugarcane crop residues	-2.2	13.2
	24	Sorghum crop residues	-1.5	3.9
	20	Hay	-1.5	8.0
	23	Millet crop residues	-1.0	2.8
	21	Maize crop residues	-0.4	6.6
Maize silage	33	Wheat crop residues	-7.4	17.0
	29	Sugarcane crop residues	-6.2	26.7
	32	Grain crop residues	-4.6	10.1
	27	Hay	-4.1	16.7
	31	Sorghum crop residues	-2.9	8.6
	28	Maize crop residues	-2.3	13.1
	30	Millet crop residues	-2.0	6.3
Hay	37	Wheat crop residues	-2.9	-1.9
	36	Grain crop residues	-1.9	-1.3
	35	Sorghum crop residues	-0.7	-0.5
	34	Millet crop residues	-0.4	-0.3

Source: Methane emissions were collected from GLEAM-i; feed costs were calculated from GLEAM-i and FAOSTAT

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Appendix B

Table B1. Enteric emissions and feed costs for cattle in Scenario 2 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	47.7	25.9	47.4	34.0	36.9	25.9	39.5	34.0
Total DM intake	kg DM/head per year	2,744	1,487	2,707	1,954	2,119	1,487	2,268	1,954
Enteric emissions	kg CO_2-eq/head per year	1,906	1,045	1,854	1,369	1,489	1,045	1,590	1,369
Feed costs	USD/head per year	2,834	1,672	2,330	2,131	2,384	1,672	2,474	2,131
Total populations in 2010									
GEtot	million MJ/year	343	211	1,689	1,711	323	257	1,403	1,708
Total intake	kt DM/year	19,748	12,120	96,388	98,328	18,565	14,750	80,631	98,154
Enteric emissions	kt CO_2-eq/year	13,717	8,517	66,003	68,900	13,046	10,365	56,500	68,778
Feed costs	million USD/year	20,403	13,635	82,985	107,231	20,885	16,593	87,931	107,040
Costs per unit	USD/kg CO_2-eq	1.5	1.6	1.3	1.6	1.6	1.6	1.6	1.6

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B2. Enteric emissions and feed costs for buffalo in Scenario 2 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	72.8	35.7	65.2	33.4	53.4	38.6	48.7	35.8
Total DM intake	kg DM/head per year	4,112	2,039	3,651	1,905	3,049	2,204	2,780	2,042
Enteric emissions	kg CO_2-eq/head per year	2,885	1,435	2,544	1,343	2,146	1,551	1,960	1,439
Feed costs	USD/head per year	4,013	2,224	3,144	2,078	3,325	2,403	3,032	2,227
Total populations in 2010									
GEtot	million MJ/year	275	144	2,190	1,193	71	88	572	723
Total intake	kt DM/year	15,543	8,205	122,725	68,168	4,029	5,011	32,679	41,293
Enteric emissions	kt CO_2-eq/year	10,905	5,774	85,497	48,046	2,836	3,527	23,033	29,104
Feed costs	million USD/year	15,166	8,948	105,660	74,339	4,394	5,465	35,638	45,031
Costs per unit	USD/kg CO_2-eq	1.4	1.5	1.2	1.5	1.5	1.5	1.5	1.5

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B3. Enteric emissions and feed costs for cattle in Scenario 3 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	48.7	26.6	48.2	34.9	37.8	26.6	40.4	34.9
Total DM intake	kg DM/head per year	2,793	1,521	2,744	1,997	2,163	1,521	2,313	1,997
Enteric emissions	kg CO_2-eq/head per year	1,961	1,082	1,896	1,416	1,538	1,082	1,640	1,416
Feed costs	USD/head per year	2,780	1,648	2,275	2,098	2,344	1,648	2,430	2,098
		Total populations in 2010							
GEtot	million MJ/year	351	217	1,717	1,756	331	264	1,436	1,753
Total intake	kt DM/year	20,104	12,402	97,702	100,524	18,948	15,094	82,225	100,346
Enteric emissions	kt CO_2-eq/year	14,119	8,820	67,529	71,260	13,475	10,734	58,288	71,133
Feed costs	million USD/year	20,007	13,440	81,025	105,597	20,532	16,356	86,374	105,410
Costs per unit	USD/kg CO_2-eq	1.4	1.5	1.2	1.5	1.5	1.5	1.5	1.5

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B4. Enteric emissions and feed costs for buffalo in Scenario 3 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	74.2	36.7	66.3	34.3	54.6	39.6	49.8	36.7
Total DM intake	kg DM/head per year	4,180	2,086	3,701	1,949	3,108	2,252	2,835	2,087
Enteric emissions	kg CO_2-eq/head per year	2,963	1,485	2,602	1,390	2,213	1,603	2,022	1,488
Feed costs	USD/head per year	3,929	2,191	3,069	2,048	3,265	2,366	2,978	2,193
		Total populations in 2010							
GEtot	million MJ/year	281	147	2227	1226	72	90	586	742
Total intake	kt DM/year	15,800	8,391	12,4397	69,743	4,108	5,121	33,325	42,210
Enteric emissions	kt CO_2-eq/year	11,201	5,974	87,467	49,727	2,925	3,646	23,761	30,096
Feed costs	million USD/year	14,850	8,814	103,164	73,262	4,316	5,379	35,006	44,340
Costs per unit	USD/kg CO_2-eq	1.3	1.5	1.2	1.5	1.5	1.5	1.5	1.5

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B5. Enteric emissions and feed costs for cattle in Scenario 4 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	49.2	26.9	48.6	35.3	38.2	26.9	40.9	35.3
Total DM intake	kg DM/head per year	2,801	1,528	2,748	2,006	2,171	1,528	2,321	2,006
Enteric emissions	kg CO_2-eq/head per year	1,988	1,100	1,917	1,438	1,562	1,100	1,664	1,438
Feed costs	USD/head per year	2,408	1,429	1,972	1,819	2,031	1,429	2,105	1,819
		Total populations in 2010							
GEtot	million MJ/year	354	220	1,731	1,778	335	267	1,452	1,775
Total intake	kt DM/year	20,159	12,462	97,862	100,976	19,014	15,166	82,493	100,797
Enteric emissions	kt CO_2-eq/year	14,312	8,967	68,253	72,399	13,681	10,912	59,147	72,271
Feed costs	million USD/year	17,336	11,650	70,231	91,537	17,789	14,177	74,839	91,374
Costs per unit	USD/kg CO_2-eq	1.2	1.3	1.0	1.3	1.3	1.3	1.3	1.3

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B6. Enteric emissions and feed costs for buffalo in Scenario 4 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	74.9	37.1	66.8	34.7	55.2	40.1	50.4	37.1
Total DM intake	kg DM/head per year	4,190	2,096	3,707	1,959	3,118	2,262	2,845	2,097
Enteric emissions	kg CO_2-eq/head per year	3,001	1,509	2,630	1,413	2,246	1,629	2,051	1,512
Feed costs	USD/head per year	3,405	1,899	2,661	1,776	2,829	2,051	2,581	1,901
		Total populations in 2010							
GEtot	million MJ/year	283	149	2244	1242	73	91	592	751
Total intake	kt DM/year	15,838	8,430	124,610	70,085	4,122	5,143	33,434	42,399
Enteric emissions	kt CO_2-eq/year	11,342	6,070	88,403	50,541	2,968	3,703	24,111	30,576
Feed costs	million USD/year	12,870	7,642	89,430	63,519	3,739	4,663	30,333	38,437
Costs per unit	USD/kg CO_2-eq	1.1	1.3	1.0	1.3	1.3	1.3	1.3	1.3

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B7. Enteric emissions and feed costs for cattle in Scenario 5 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	49.7	27.3	49.0	35.7	38.7	27.3	41.3	35.7
Total DM intake	kg DM/head per year	2,845	1,557	2,782	2,043	2,209	1,557	2,360	2,043
Enteric emissions	kg CO_2-eq/head per year	2,014	1,117	1,936	1,460	1,584	1,117	1,687	1,460
Feed costs	USD/head per year	1,961	1,169	1,599	1,487	1,658	1,169	1,718	1,487
		Total populations in 2010							
GEtot	million MJ/year	358	222	1,744	1,799	339	271	1,468	1,796
Total intake	kt DM/year	20,478	12,698	99,077	102,817	19,350	15,453	83,896	102,635
Enteric emissions	kt CO_2-eq/year	14,496	9,108	68,942	73,494	13,879	11,084	59,969	73,363
Feed costs	million USD/year	14,118	9,532	56,922	74,823	14,526	11,601	61,053	74,690
Costs per unit	USD/kg CO_2-eq	1.0	1.0	0.8	1.0	1.0	1.0	1.0	1.0

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B8. Enteric emissions and feed costs for buffalo in Scenario 5 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
		Per head in 2010							
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	75.6	37.6	67.3	35.1	55.8	40.5	50.9	37.6
Total DM intake	kg DM/head per year	4,251	2,134	3,753	1,995	3,171	2,302	2,893	2,135
Enteric emissions	kg CO_2-eq/head per year	3,036	1,532	2,657	1,435	2,277	1,653	2,080	1,535
Feed costs	USD/head per year	2,768	1,553	2,156	1,452	2,308	1,675	2,105	1,554
		Total populations in 2010							
GEtot	million MJ/year	286	151	2,261	1,257	74	92	599	760
Total intake	kt DM/year	16,068	8,585	126,143	71,385	4,191	5,235	34,001	43,168
Enteric emissions	kt CO_2-eq/year	11,477	6,163	89,293	51,323	3,009	3,758	24,445	31,036
Feed costs	million USD/year	10,462	6,248	72,472	51,949	3,050	3,810	24,744	31,414
Costs per unit	USD/kg CO_2-eq	0.9	1.0	0.8	1.0	1.0	1.0	1.0	1.0

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B9. Enteric emissions and feed costs for cattle in Scenario 6 in 2010

		Dairy cattle				Beef cattle			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	51.2	28.3	50.0	37.0	40.0	28.3	42.6	37.0
Total DM intake	kg DM/head per year	2,914	1,608	2,833	2,106	2,271	1,608	2,424	2,106
Enteric emissions	kg CO_2-eq/head per year	2,091	1,170	1,994	1,526	1,653	1,170	1,757	1,526
Feed costs	USD/head per year	1,766	1,061	1,431	1,347	1,499	1,061	1,551	1,347
Total populations in 2010									
GEtot	million MJ/year	368	231	1,782	1,863	350	281	1,514	1,860
Total intake	kt DM/year	20,978	13,107	100,883	105,984	19,896	15,951	86,157	105,796
Enteric emissions	kt CO_2-eq/year	15,050	9,538	70,997	76,829	14,478	11,608	62,456	76,692
Feed costs	million USD/year	12,714	8,649	50,949	67,799	13,129	10,526	55,115	67,679
Costs per unit	USD/kg CO_2-eq	0.8	0.9	0.7	0.9	0.9	0.9	0.9	0.9

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Table B10. Enteric emissions and feed costs for buffalo in Scenario 6 in 2010

		Dairy buffalo				Beef buffalo			
		Grassland		Mixed		Grassland		Mixed	
		AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM	AF	AM, RF, RM
Per head in 2010									
Herd size	heads/year	7,198	8,153	35,608	50,330	8,760	9,922	35,545	50,241
GEtot	MJ/head per year	77.6	38.9	68.7	36.4	57.6	41.9	52.5	38.9
Total DM intake	kg DM/head per year	4,346	2,201	3,821	2,059	3,256	2,371	2,971	2,200
Enteric emissions	kg CO_2-eq/head per year	3,144	1,602	2,736	1,501	2,370	1,727	2,166	1,604
Feed costs	USD/head per year	2,487	1,408	1,930	1,317	2,083	1,517	1,900	1,408
Total populations in 2010									
GEtot	million MJ/year	293	157	2,310	1,303	76	95	618	787
Total intake	kt DM/year	16,426	8,854	128,438	73,666	4,303	5,392	34,917	44,489
Enteric emissions	kt CO_2-eq/year	11,882	6,446	91,947	53,710	3,133	3,926	25,458	32,437
Feed costs	million USD/year	9,402	5,664	64,866	47,125	2,753	3,450	22,337	28,460
Costs per unit	USD/kg CO_2-eq	0.8	0.9	0.7	0.9	0.9	0.9	0.9	0.9

Source: Feed costs were calculated from FAOSTAT; other information was calculated and collected from GLEAM-i

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Turnitin result

印度養牛產業之腸道發酵甲烷排放減量潛力

與成本分析

Mitigation potential and costs of enteric methane

emissions from Indian bovine sector

Student: 陳方婕

Advisor: 李慧琳

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