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EMAG - National model for evaluating environmental impacts of cattle production systems in Uruguay

EMAG - Modelo nacional para evaluar impactos ambientales de sistemas de producción ganadera en Uruguay

EMAG - Modelo nacional de evaluação de impactos ambientais dos sistemas de produção pecuária no Uruguai

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Abstract

Cattle and sheep systems in Uruguay and worldwide are challenged to reduce their environmental footprint while increasing efficiency and production. To achieve this challenge, user-friendly tools are needed that can translate research findings into practical information that could improve decision making by farmers and advise different stakeholders. Despite this, there are a limited number of applied environmental models in other countries and they are typically based on productive, high-quality pasture/crop-feed systems with relatively high inputs. In contrast, cattle and sheep production in Uruguay is largely associated with extensive grazing systems on unique natural grassland systems of relatively poor feed quality and often with no nutrient inputs in fertilizers. Thus, there is a need for a model that can take account for these types of systems and bring together relevant country-specific data to provide information of relevance for Uruguay. The EMAG (*Evaluación Medio Ambiental Ganadera*) model accounts for multiple environmental and resource use indicators of nutrient (nitrogen and phosphorus) balances and losses, greenhouse gas emissions and use of fossil energy. Results are provided on a per-hectare and per-kg product basis. This decision support tool for cattle and sheep farmers systems is based on life cycle assessment (LCA) methodology from "cradle-to-farm gate" for all resources use indicators. It uses national parameters and in case of lack of information is supplied from international research in pastoral systems. The model use for environmental methodology tier 2 animal energy model to account for key animal productivity and management practices. EMAG is a user-friendly model that requires basic information for a farm system divided into land use (forage types used uniquely for natural grassland in Uruguay), animal management (beef cattle and sheep), farm inputs (fertilizers, supplementary feeds, seeds and agrochemicals) and fossil energy (fuel and electricity) used in the system. EMAG can help to identify hot-spots of emissions and resource use, as well as to evaluate changes over time. In addition, it can be used to test cattle or sheep management practices or evaluate mitigation options within the system. By providing multiple indicators, EMAG can be used to provide information to avoid "trade-offs" between environmental impacts when assessing future options. As an example of usability, the paper reports a case study which showed potential benefits of improving environmental efficiency and note interesting result around negative P balance when increase productivity in a system. In summary, EMAG is a decision-support tool developed with the objective of evaluating the environmental performance of cattle and sheep systems, that would help farmers in decision making and different stakeholders according to their interest.

Keywords: environment, grazing systems, cattle, model

Resumen

Los sistemas ganaderos en Uruguay y en todo el mundo tienen el desafío de reducir su huella ambiental al tiempo que aumentan la eficiencia y la producción. Para lograr este desafío, se necesitan herramientas fáciles de usar que puedan traducir los hallazgos de la investigación en información práctica que pueda mejorar la toma de decisiones de los productores y asesorar a diferentes actores interesados. A pesar de que existe un número limitado de modelos ambientales utilizados en otros países, por lo general, se basan en sistemas productivos donde existen forrajes de alta calidad/cultivos y con alto uso de insumos. En contraste, la producción ganadera en Uruguay está asociada en gran medida con sistemas de pastoreo extensivos, basados en el uso de forrajes únicos en el mundo donde la calidad del alimento es relativamente pobre y prácticamente sin agregado de fertilizantes. Por lo tanto, en este escenario existe la necesidad de un modelo que pueda tener en cuenta este tipo de sistemas y que reúna datos relevantes específicos nacionales con el objetivo de proporcionar información relevante para Uruguay. El modelo EMAG (Evaluación Medio Ambiental Ganadera) cuenta con múltiples indicadores ambientales y de uso de recursos de balances como: pérdidas de nutrientes (nitrógeno y fósforo), emisiones de gases de efecto invernadero y uso de energía fósil. Los resultados se proporcionan por hectárea y por kg de producto. Esta herramienta de apoyo a la toma de decisión para sistemas ganaderos (vacuno y ovinos) se basa en la metodología de evaluación de análisis de ciclo de vida (ACV) desde la «cuna a la portera del establecimiento» para todos los indicadores de uso de los recursos. Utiliza parámetros nacionales y, en caso de falta de información, se obtiene de investigaciones internacionales en sistemas pastoriles. El modelo utiliza para la metodología ambiental la referente de energía animal de nivel 2 para evaluar las prácticas clave de producción y manejo animal. EMAG es un modelo fácil de usar que requiere información básica de un sistema dividido en: el uso de la tierra (tipos de forraje utilizados exclusivamente para pasturas naturales en Uruguay), manejo de animales (ganado vacuno y ovino), insumos utilizados (fertilizantes, alimentos complementarios, semillas y agroquímicos) y energía fósil (combustible y electricidad) utilizada en el sistema. EMAG puede ayudar a identificar puntos altos de emisiones ambientales y uso de recursos naturales, así como evaluar cambios a lo largo del tiempo. Además, se puede utilizar para probar distintas prácticas de manejo de ganado vacuno y ovino o evaluar las opciones de mitigación dentro del sistema. Al proporcionar múltiples indicadores, EMAG se puede utilizar para proporcionar información para evitar «compensaciones» entre los impactos ambientales al evaluar las opciones futuras. Como ejemplo de usabilidad del modelo, el documento presenta un estudio de caso que muestra los beneficios potenciales de mejorar la eficiencia ambiental con un resultado interesante en torno al balance de fósforo negativo cuando se incrementa la productividad en un sistema. En resumen, EMAG es una herramienta de apoyo a la toma de decisiones desarrollada con el objetivo de evaluar el desempeño ambiental de los sistemas ganaderos que ayudaría a los agricultores en su toma de decisiones y a diferentes actores interesados.

Palabras clave: medioambiente, sistemas de pastoreo, ganado, modelo

Resumo

A pecuária no Uruguai e no mundo é desafiada a reduzir seu impacto ambiental, aumentando sua eficiência e produtividade. Para alcançar esse objetivo são necessárias ferramentas de fácil utilização que possam traduzir as descobertas da pesquisa em informações praticas para a melhoria na tomada de decisão pelos agricultores e assistência às diferentes partes interessadas. Entretanto, há um número limitado de modelos ambientais aplicados em outros países, normalmente baseados em sistemas produtivos de alta qualidade para pastagens / culturas, com uso relativamente alto de insumos. Em contraste, a produção de bovinos e ovinos no Uruguai está amplamente associada ao pastoreio extensivo em sistemas naturais de pastagens nativas, com qualidade nutricional relativamente baixa e geralmente sem o uso de fertilizantes. Portanto, é necessário um modelo que considere esse tipo de sistema e que reúna dados relevantes de cada país para fornecer informações relevantes às condições do Uruguai. O modelo EMAG (*Evaluación Medio Ambiental Ganadera*) reúne vários indicadores de uso ambiental e de recursos como balanços de perdas de nutrientes (nitrogênio e fósforo), emissão de gases do efeito estufa e uso de energia fóssil. Os resultados são fornecidos por hectare e por kg produzido. Essa ferramenta de apoio à decisão para sistemas pecuários (bovinos e ovinos) é baseada na metodologia de avaliação do ciclo de vida (LCA) do "berço à porteira" para todos os indicadores de uso de recursos. Utiliza parâmetros nacionais e, em sua na ausência, obtêm-se de pesquisas internacionais em sistemas pastoris. O modelo utiliza como metodologia ambiental a referência de energia para animais de nível 2 na avaliação das principais práticas de produtividade e manejo animal. O EMAG é um modelo de fácil uso e que requer informações básicas para um sistema agrícola dividido em uso da terra (tipos de forragem usados exclusivamente para pastagens naturais no Uruguai), manejo animal (bovinos e ovinos), insumos agrícolas (fertilizantes, alimentos suplementares, sementes e agroquímicos) e energia fóssil (combustível e eletricidade) usada no sistema. O EMAG pode ajudar a identificar pontos críticos de emissão e uso de recursos, bem como avaliar mudanças ao longo do tempo. Além disso, pode ser usado para testar práticas de manejo de bovinos e ovinos ou avaliar opções de mitigação dentro do sistema. Ao fornecer vários indicadores, o EMAG pode ser usado para fornecer informações para minimizar "compensações" entre impactos ambientais ao avaliar opções futuras. Como exemplo de usabilidade, o artigo relata um estudo de caso no qual os benefícios potenciais de melhoria na eficiência ambiental evidenciam resultados interessantes em torno do balanço P negativo decorrente do incremento da produtividade em um sistema. Em resumo, o EMAG é uma ferramenta de apoio à definição de ações desenvolvida com o objetivo de avaliar o desempenho ambiental dos sistemas pecuários para auxílio dos agricultores na tomada de decisões e nas diferentes partes interessadas, de acordo com seus interesses.

Palavras-chave: meio ambiente, sistemas de pastoreio, pecuária, modelo

1. Introduction

The environmental impacts of livestock systems have become an important issue of public and scientific debate worldwide, for more than a decade[1]. Global challenges from SDGs (Sustainable Development Goals[2]) lead to the need to produce more food from less resources with less environmental impacts. In this sense, livestock production has a very important role to provide sustainable food to humanity, considering the projected increase in world population. However, currently the subject that arouses greater interest and international debate is limiting the use of natural resources, under the statement that more efficient production can reduce impacts on climate change and other environmental impacts[3].

Uruguay's cattle sector is a critical component of Uruguay's agricultural sector, responsible for approximately half of its agricultural gross domestic product (GDP), which is 8-9% of the national GDP[4]. Moreover, for a country of just 3.4 million people, it supplies 5% of the beef on the global market (in terms of weight), making up 20% of the total value of Uruguay's exports ($1.5 billion)[4]. In addition to its economic and social importance, Uruguayan cattle systems are managed under free-range systems with a low degree of intensification, where natural pastures are the main feed resource for cattle. However, this sector has a significant environmental footprint[5][6][7][8]. In the last two decades these systems have needed to incorporate other technologies (supplementation, introduced pasture, etc.) to increase production or improve efficiency and keep competitiveness. This transition toward more complex and intensive systems may lead to different states of degradation of natural resources.

In many agricultural countries such as New Zealand, Canada and Ireland, where cattle are an important production system, the impacts of intensification on the environment is a common concern. To address this problem, the assessment and quantification of environmental emissions have become important to determine their impacts and to understand the potential benefits of mitigation options. Currently, there are some practical models that can be used in livestock production, such as Overseer in New Zealand[9] and Holos in Canada[10], which are based on biophysical models to evaluate changes in production and estimate environmental emissions. However, this limited number of applied environmental models are based on productive, high quality pasture/crop-feed systems with relatively high inputs. In contrast, cattle and sheep production in Uruguay is largely associated with extensive grazing systems on unique natural grassland systems of relatively poor feed quality and often with no nutrient inputs in fertilizers. Thus, there is a need for a model that can take account of these systems and that brings together country-specific data to provide information of relevance for Uruguay.

In summary, there is a need for a tailored environmental tool for Uruguay that should: identify "hotspots" of resource use and environmental emissions, translate information into useful and practical recommendations, account for changes over time, test management/mitigation options, and enable avoidance of "trade-offs" between impacts when assessing future options. This paper gives an overview of why a national model for cattle systems is needed and the specification of a complete animal biology model with modules for estimating resource use and environmental emissions. It includes the variables, equations and parameter values that are used in the tool, the validation of this model with international models, and illustrates how it works using a case study. Finally, a description is given of the features that make this tool suitable as a decision support tool for Uruguayan conditions.

2. Materials and methods

2.1 Principles of EMAG development and construction

The cattle and sheep environmental assessment, EMAG (*Evaluación Medio Ambiental Ganadera*, in Spanish), is a decision support tool that allows simulation of the environmental performance of cattle and sheep systems, accounting for the complexity of the national systems and diverse use and inputs. The EMAG model was developed within the framework of the Uruguayan Family Farm Improvement Project UFFIP (http://www.uffip.uy/) with the objective of evaluating resource use and environmental emissions from livestock systems that would be a useful support to improve knowledge of producers and technicians, as well as to enable them to understand the effects of potential changes to their systems and create awareness of the importance of environmental aspects. To illustrate the usefulness of EMAG, a case study of a cattle and sheep system from the UFFIP project is presented on section 3.1. This model meets the current methodology requirements according to international guidelines(11)(12) to evaluate environment emissions.

EMAG is a model that was designed with the objective of evaluating the productive and environmental performance of cattle and sheep systems over one year, and estimating changes over time of the different environmental indicators according to changes in management practices of the system. EMAG was developed considering principles of:

- Ease of use to farmers or their advisors; it is based on easily collected information from inputs that farmers know, or can be readily obtained, otherwise reasonable default values are supplied. The model contains a large database of national research data.

- Annual time scale; the model was developed as an annual estimation tool.

- Farm scale; the model operates at a farm scale considering different land use and types of pasture. The model has a constraint that it doesn´t track nutrient movement within the farm between paddocks, but it includes nutrients brought in from inputs and losses from the farm system.

- Ability to evaluate mitigation options; a range of mitigation scenarios have been added to the model. As well, it provides the user with a set of recommendations to implement mitigation strategies.

The following indicators based on productivity and sustainability were developed:

1. Biophysical production information

- animal production (meat and wool)
- stocking rate
- pasture dry matter production

2. Resource use efficiency

- fossil energy use (MJ/ha and MJ/kg product sold)
- nutrients (nitrogen [N] and phosphorus [P]) use and farm nutrient balance (kg N/ha and kg P/ha)

3. Environmental emissions

- Greenhouse gases (GHG emissions/ha and per kg product sold)
- N & P loss to waterways (kg N/ha and kg P/ha)

2.2 Farmer information required

The model inputs are divided into land use, animal management, farm inputs and fossil energy used in the system.

The total farm area is defined and can be separated into different block areas according to different forage types used. This can account for natural grasslands, natural grasslands oversown with legumes, improved grassland species (as biannual or perennial pastures), annual forage crops, as well as crops for grazing or grain purpose. The soil type for each block area must be defined.

For each introduced forage resource, the model user must either enter the annual dry matter production, or select default values from satellite monitoring for the region(13) or from national research information(14). The % (by weight) of legume in grassland must be defined by the user or the model can provide default values.

In reference to animal management the model accounts for beef cattle and sheep. For each animal type, the number and category changes (including deaths) during the year are required, as well as the live-weights at the beginning and end of the year, % calving or lambing, and birth weights. Animal purchases, sales and removals (death or eaten) need to be recorded.

For inputs used during the year, information is needed on the type and amounts of fertilizers, supplementary feeds, seeds and agrochemicals. Finally, the direct use of fuel and electricity is required, accounting for transport of animals and inputs, and fuel for energy generation. Machinery activities are entered on an area basis to estimate indirect fuel use.

2.3 How EMAG works

EMAG methodology for analyzing environmental emissions is based on using life cycle assessment (LCA), with the system boundary defined from "cradle-to-farm gate"[(15)]. LCA is the most appropriate approach to identify the hot-spots within the system and options for innovation and mitigation, as well as to improve the understanding of complex meat systems[(11)(12)]. It uses data on farm system and inputs for estimating environmental impacts throughout the life cycle related to a product (beef, sheep meat and wool). Figure 1 shows the various factors included in the GHG estimation in EMAG.

A critical component evaluating a farm system and environmental emissions is animal feed consumption. Thus, an animal biology model (tier 2) is used to determine dry matter intake (DMI) according to animal category, animal productivity, diet quality and management circumstances.

The equation for estimating DMI for growing and finishing cattle is[(16)]:

$$DMI = BW^{0.75} \cdot [(0.2444 \,.\, NE\,ma - 0.0111 \,.\, NE\,ma^{2} - 0.472)/ NE\,ma]$$

Where: DMI = dry matter intake, kg day^{-1}
BW = live body weight, kg
NEma = estimated dietary net energy concentration of diet, MJ/kg

DMI for mature beef cattle is calculated using:

$$DMI = BW^{0.75} \cdot [(0.0119 \,.\, NE\,ma^{2} + 0.1938)/ NE\,ma]$$

The equation for estimating DMI for sheep[(16)] is:

$$DMI = GE/\text{Energy density of the feed}$$

Where: GE is calculated for each animal subcategory[(17)]

Energy density of the feed is a default value of 18.45 MJ kg^{-1} of dry matter

Total energy requirements are determined by the model. The energy from supplementary feed is subtracted (accounting for wastage and NE concentration) and the remainder is assumed to be derived from grazing and is apportioned between the different forage types across block areas according to the relative DM production and utilization values in Table 1. In all cases the model assumes different percentages of feed utilization according to different feed types (Table 1). The model may, alternatively, be used with any external or internal feeds that have been supplied to the system (e.g. supplements or concentrates), where the user can provide quality characteristics from the feed. However, in all cases the model assumes same quality between categories.

The feed intake is used to calculate methane from enteric fermentation (using tier 2 IPCC 2006 emission factors), methane from manure management (based on volatile solids calculated using feed digestibility concentration) and IPCC 2006 emission factors[(11)(12)].

The amount of DMI is multiplied by the average nitrogen concentration (percentage nitrogen) of the diet (weighted according to the relative proportions of different feed types in the diet) to get the amount of nitrogen consumed (crude protein/6.25). Nitrogen output that is retained in product(s) (meat, hide, blood and milk) is then subtracted from the nitrogen consumed to calculate the amount of nitrogen excreted and that is linked to IPCC[(17)] emission factors for nitrous oxide (direct and indirect emissions).

The equation for estimating N excreted from cattle and sheep[(17)] is:

kg N excreted = kg N consumed – kg N in products

Indirect nitrous oxide emissions are estimated using leaching and ammonia volatilization emission factors[17]. Nitrous oxide emissions from crop residues are also estimated, as well as the on-farm direct carbon dioxide emissions from urea fertilizer and lime application based on their composition[17].

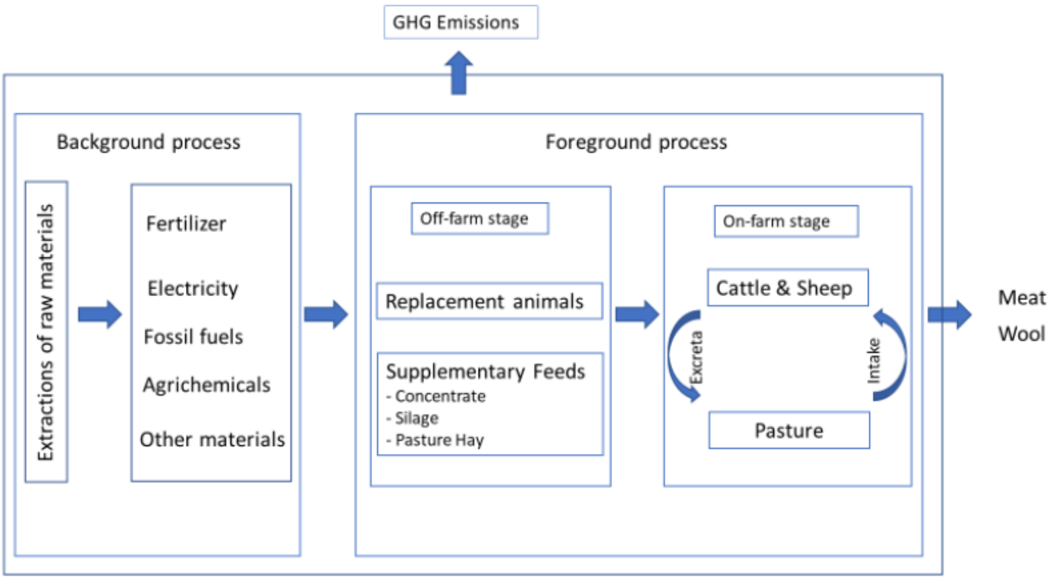
Table 1. Assumed percentage utilization by animals of different feed inputs

Feed type	% Utilization*
Natural grasslands	0.50
Natural grasslands oversown legumes	0.55
Pastures	0.60
Annual crop feeding	0.65
Silage	0.80
Hay	0,80
Grain/Supplements	0.90

(*) _ based on expert opinion

The presence of housing of animals is not relevant for national cattle systems and the only relevant infrastructure are cattle yards, shearing facilities, wire fencing, etc., so it is assumed that CO_2 emissions from infrastructure are negligible following IPCC[17] recommendations. In the same way, emissions from machinery, equipment or buildings were excluded based on lack of currently available data and because it is assumed that they have no significant impact[18]. The off-farm GHG sources considered are embodied emissions for inputs used on the farm. The source of the supplementary feeds brought onto farms is not always known when purchased. Therefore, based on recommendation from Wheeler and others[19] and FAO[12], the embodied emissions for supplementary feeds are based on the rate supplied by the user (in tons) and typical LCA-based emission factors (kg CO_2 equivalents per kg DM) for growing the feed, plus any manufacturing and transportation required considering average distance (100 km) according to country size (Table 4). In the case of fertilizer a similar process is used, developed from the beef national carbon footprint study[20], using an LCA study on fertilizer accounting for overseas transport of sourced material used[21] and manufacturing and transport in Uruguay (Table 3). To account for animals sourced from off-farm, embodied emissions are difficult to account for since previous animal management is unknown. Thus, to avoid mistake from this source, the GHG product footprint calculation is based on net animal product exported from the system, i.e., subtracting the purchased liveweight[11][12].

Figure 1. Diagram of GHG emissions accounted for in the production systems



The GHG emissions from all sources, covering animal product, feed production, production and use of all inputs, and energy use are then summarized and divided by the farm area to get per-hectare results. For calculation of GHG emissions per kg product, an allocation approach is used. Firstly, where cattle and sheep are grazed together the model allocates emissions between cattle and sheep based on their relative DMI[11][12]. In the case of sheep, the total sheep GHG emissions are allocated between LW (liveweight) sold for meat and wool, using the latest methodology from LEAP[11] based on protein mass allocation.

Finally, all GHG emissions are expressed in CO_2 equivalent units to account for global warming potential of each gas assuming a 100-year time horizon (25 for CH_4, 298 for N_2O and 1 for CO_2)[17].

The fossil energy demand model is estimated from the energy demand of the fossil fuels of the system (38.5 MJ/lts diesel, 34,2 MJ/lts fuel), electricity demand of the system taking into account the national energy matrix (3.6 MJ/kWh), energy demand for manufacturing, and transportation of goods and services used by the system[11][12].

For example, a farm of 200 ha that export 90 kg meat/ha/yr consumes annually 2000 l diesel and 5000 kWh electricity.

Model calculation:

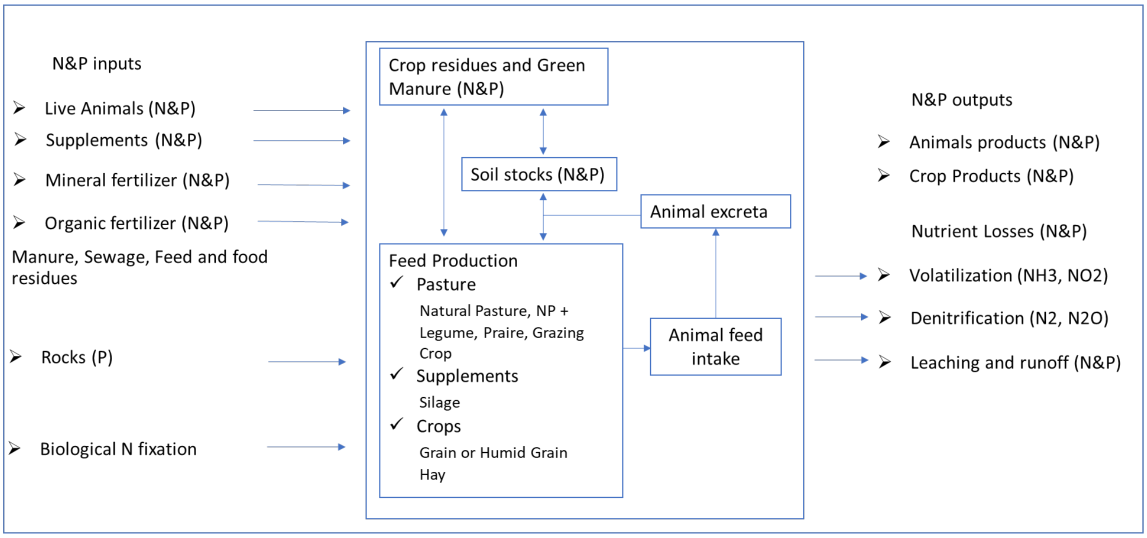
2000 * 38.5 = 77.000 MJ/yr from fuel

5000 * 3.6 = 18.000 MJ/yr from energy consumption

Total fossil energy demand is: 77.000 + 18.000 = 95.000 MJ/yr or 475 MJ/ha/yr or 5.3 MJ/kg meat/yr

For the nutrient model, external inputs (Figure 1) and outputs (product) of N and P from the system are estimated, as well as potential losses under the different forms of N, and particulate and soluble P (Figure 2).

Figure 2. Diagram of N and P flows in feed production systems



Calculation of nutrient balances is based on the sum of all outputs (N&P) minus that for inputs, as shown in Figure 2 based on LCA methodology. Table 2 represents N&P parameters used by the model. Natural N input from N fixation is calculated from the percentage of legume in forages and the area of land use and DM production[22]. Atmospheric deposition is calculated directly from the amount of hectares and an annual N deposition factor[23]. For P inputs related to supplements the same procedure is used as for N, in the case of fertilizer it is converted from P_2O_5 content (tons) into P. For the N&P output account, it uses the content of each nutrient in meat sold or eaten, and wool produced by the system. Farm P emissions are dominated by runoff of soil-P, as calculated by a country-specific tier-2 model[24]. This was based on 0.47 kgP/ha of particulate–P from erosion (1 ton ha/yr) using a country-specific erosion model[25] and 0.36 kg P/ha of dissolved-P, where 0.06 are losses from the soil (3 ppm P Bray I).

2.4 Input default values

For some feed parameters, the model provides national research information for cases where information is not available (e.g. annual average dry matter production, pasture quality, percentage of legume or quality of supplements). The environmental burden (energy, GHG and nutrients) from the production of inputs is provided based on national information and default values from research in case of lack of information (Table 3).

Table 2. Internal parameters from model

Parameters	Values
N fixation (kg N/t DM)[22]	0.054
N deposition (kgN/ha/yr)[23]	5.0
P_2O_5 content (tonnes) into P (kg)	0.437
Protein in meat (%/kgLW)[26]	20
N wool (kg N/kg wool)[27]	0.15
P in meat (%/kg LW)[28]	0.73
P wool (kg P/kg wool)[27]	0.014

Table 3. Type of fertilizer used and their environmental embodied emissions

Fertilizer (N-P-K-S)	Energy (MJ/kg)	GHG (CO_2e/kg)	N (% by weight)	P_2O_5 (% by weight)
7-0-40-0[20][21]	10.10	0.79	7	40
Diammonium phosphate[20][21]	10.10	0.79	18	46
Monoammonium phosphate[20][21]	10.10	0.75	12	52
Phosphate rock[20][21]	3.00	0.24	--	28
Superphosphate[20][21]	5.58	0.37	--	18
Urea[20][21]	22.55	0.79	46	---

Table 4. Supplement feeds and their environmental embodied emissions

Supplements feed	Energy (MJ/kg)	GHG (CO_2e/kg)	N %	P %
Wheat Bran[14][29]	5.70	0.12*	2.75	0.68
Rice Bran[14][29]	5.70	0.03*	2.43	1.12
Sunflower expeller[14][29]	5.70	0.83*	5.80	0.83
Soybean expeller[14][29]	5.70	0.17*	7.31	0.43
Concentrate (adult animals)[14][20][29]	5.20	0.12*	1.92	0.10
Concentrate (young animals)[14][20][29]	5.20	0.12*	2.40	0.10
Concentrate (calves)[14][20][29]	6.40	0.17*	2.88	0.74
Lucerne hay[14][29]	0.58	0.01*	3.01	0.24
Low quality hay[14][20][29]	1.36	0.01*	0.64	0.07
Pasture hay[14][29]	0.58	0.01*	1.62	0.19
Maize grain[14][29]	0.90	0.17*	1.44	0.25
Sorghum grain[14][29]	1.00	0.07*	1.38	0.30
Maize humid grain[14][20][29]	1.35	0.06*	1.33	0.21
Maize silage[14][29]	0.36	0.09*	1.26	0.17

(*) _ Data from GHG emissions obtained from modelling each supplement production through the tool.

Table 5. Herbicides and insecticides and their environmental embodied emissions

Herbicides and Insecticide	Energy (MJ/lt)	GHG (CO_2e/lt)
2-4D amine[20][29][30]	62.23	2.94
Atrazine[20][29][30]	67.00	6.49
Cypermetin[20][29][30]	64.50	10.00
Dual[20][29][30]	170.88	18.26
Glyphosate[20][29][30]	58.68	11.27
Flumetsulam[20][29][30]	67.00	18.25
Lorsban[20][29][30]	123.84	14.79

Table 6. Seeds used and their environmental embodied emissions

Seeds	Energy (MJ/kg)	GHG (CO_2e/kg)
Lucerne[20][29]	87.00	0.10
Oat[20][29]	18.60	0.39
Dactylis[20][29]	18.60	0.20
Fescue[20][29]	18.60	0.20
Lotus Corniculatus[20][29]	87.00	0.13
White clover[20][29]	87.00	0.13
Red clover[20][29]	87.00	0.06
Moha[20][29]	18.60	0.10
Ryegrass[20][29]	18.60	0.14
Wheat[20][29]	7.04	0.22

2.5 Internal parameters

Animal GHG emissions are calculated using emission factors, primarily from national research and default Intergovernmental Panel on Climate Change (IPCC) values where there is a lack of information. In the case of enteric methane emissions from beef cattle, 6,5% (CH_4 conversion factor) is used according to Dini and others[31][32] and Orcasberro and others[33]. For GHG emissions from supplement production, data is provided from previous national research from the Agriculture Ministry beef carbon footprint study[20]. For fossil energy use, parameters are based on national information, 2,98 kg CO_2e/lt fuel and for electricity the national energy matrix (3% from fossil energy) is considered[34]. For machinery use on farm, fossil fuel consumption for each operation data recommended from Uruguayan Chamber of Agricultural Services is used[35]. Energy parameters from fertilizer manufacturing are used based on NZ research database[21], whereas for supplements production national research is used[29].

2.6 Quality of the different pastures and forages

Cattle and sheep production in Uruguay are largely associated with extensive grazing systems on unique natural grassland systems of relatively poor feed quality and often with no nutrient inputs in fertilizer. In the following table (Table 7) there are representative default values for the quality of the different pastures and forages unique for Uruguay — including digestibility, crude protein, ME and P concentrations.

Table 7. Quality of pastures and forages

Type of Pastures and Forages	Digestibility %	Crude Protein %	ME Mcal/kg DM	P conc. %
NG Areniscas ladera alta[36][37]	52,58	8,03	2,10	0,15
NG Areniscas bajo[36][37]	52,58	6,22	2,10	0,12
NG Basalto medio[38][39]	55,80	8,03	2,10	0,14
NG Basalto profundo[38][39]	55,80	9,43	2,10	0,14
NG Basalto superficial negro[38][39]	55,80	8,03	2,10	0,14
NG Basalto superficial rojo[38][39]	55,80	8,03	2,10	0,14
NG Cristalino profundo[40]	51,20	8,60	2,10	0,13
NG Lomadas este[41]	52,0	8,80	2,10	0,15
NG + LS[40][42]	57,40	12,35	2,20	0,30
NG + WC + LC[40][42]	59,30	13,23	2,20	0,30
Lucerne[43]	65,60	23,30	2,50	0,24
Oat[38][44]	72,60	16,73	2,50	0,22
Ryegrass[38][44]	72,60	18,50	2,70	0,30
Maize forage[45]	62,00	8,99	2,30	0,30
Sorghum forage[45]	62,00	8,99	1,80	0,30
Wheat forage[45]	72,00	17,60	2,30	0,26
Chicori + RC[45]	65,60	33,60	2,60	0,25
WC+LC+F pasture[45]	70,00	18,10	2,40	0,31
Oat +Ry + RC[45]	72,00	17,60	2,60	0,26
WC+LC+Ry pasture[43]	70,00	18,10	2,40	0,31
Lucerne silage[14]	51,71	18,32	2,3	0,27
Maize silage[14]	66,29	7,30	2,38	0,21
Sorghum silage[14]	58,26	7,55	2,20	0,18
Moha hay[14]	59,79	12,66	2,35	0,19

NG_Natural grassland, LS_Lotus Subiflorus, LC_Lotus Corniculatus, WC_White clover, RC_Red clover, Ry_Ryegrass, F_Fescue

2.7 EMAG validation process

To validate EMAG model two published studies with very good data were selected[46][47] . The New Zealand study referred to a New Zealand typical system, of beef and sheep on hill country land[46]. The published data make reference to a survey from North Island hill country which makes up about a third of New Zealand beef production. To estimate environmental outputs, the Overseer model was used[9]. The second study referred to a Canadian cow-calf dryland prairie farm where steers and heifers are fattened on high-grain diets in a feedlot[47]. This production system is representative of western Canada beef farms. More than 75% of Canada cow herd and feedlot cattle are in the four western provinces. To estimate GHG from this system the HOLOS model was used[10]. Those country models had been validated against research within their own countries.

The New Zealand published data was entered into the EMAG model and the outputs were compared to the published ones. EMAG and Overseer outputs were very similar in terms of energy and nutrients with just a slightly difference in GHG/ha and GHG emission intensity, probably because of pasture quality (Supplementary tables. S1). Canadian data were also entered into EMAG and Overseer and the outputs of the three models were compared. A good agreement was found on GHG/ha and GHG emission intensity between the three models. Nutrients and energy outputs were not available for the published study, so it was not possible to make that comparison (Supplementary tables. S2).

The comparisons made reflected that EMAG is a robust model that could be used to estimate environmental outputs of beef and sheep systems.

3. Results and discussion

3.1 Case study

The case study used is an extensive system of mixed (cattle and sheep) breeding, characterized by year-round mating (spring, summer and winter), low pregnancy rate and cull cows sold in low condition. The farm has a high proportion of the area composed of shallow basalt soils.

Table 8 shows the characteristics of the system and management practices that were used at the beginning of the project (baseline) and at the end of it. At the beginning of the project the system had 88% of the area in natural grasslands and 12% with improvements of natural grasslands with legume (Lotus subiflorus). It had excessive use of supplements feed (wheat bran, lucerne hay, sorghum grain and 16% of crude protein concentrate) and minerals, at a rate of 73 kg/ha/year. The goal pursued by the producer was to promote an improvement in productivity while taking care of the environment. This included the efficient use of resources without modifying or reducing the input/output ratio. At the end of the project, a restricted spring-summer mating system was established, the whole area of legumes was increased up to 17% of total land and the use of supplements was reduced by almost 35% during the year.

Table 8. Summary of the change in management over time in the case study farm. Start year was 2014/2015, while the project ended in 2016/2017.

Management practice	Year 2014/15	Year 2016/17
Land use_(%)	NG (88), NG+LS (12)	NG (83), NG+LS (12), NG+LP (5)
Supplements use (kg/ha/yr)	77	48
Stocking rate (LU/ha/yr)	0,7	0,65
Fertilizer inputs (tonnes/yr)*	1.05	1.7
Grazing practices	No grazing plan	Feed budgeting used
Husbandry practices	Without mating control	Spring-summer mating
	Sell cull cows after weaning	Fattening cull cows
	3-4 yr old cows at first calving	3 yr old cows at first calving

NG_Natural grassland, LS_Lotus subiflorus, LP_ Lotus pedunculatus LU_Livestock unit (based on an adult cow of 380 kg LW that weans one calf per year). (*)_ Fertilizer was used only on lotus pasture area, in 14/15 was 1 ton of 7-0-40-0 and 0.05 ton of diammonium phosphate and in 16/17 was 1.7 tonnes of 7-0-40-0.

At the end of the study in 2016/2017, meat production (cattle and sheep) had stabilized at an additional 25% compared to 2014/2015. This was associated with an adjustment in stocking rate according to DM production, which resulted in better cow pregnancy and fattening of cull cows. Regarding outputs from EMAG, Table 9 shows a reduction in nitrogen losses, although the use of fertilizer has increased. This is probably explained due to an improvement in the use efficiency and reduction in stocking rate, meaning less N excreted by animals, which is the main source of N losses. In the case of P, the high negative balance is explained due to low inputs to the system, with increases of meat production making the balance of the system even more negative. This would indicate a system with possible slow mining of fertility (at least for phosphorus) which could affect long-term sustainability.

Table 9. Result of the use of EMAG and changes in the indicators from the production system

	Year 2014/15		Year 2016/17	
Calf weaning rate (%)	73		76	
Lambing rate (%)	94		113	
Meat production (kg/ha)	92		119	
GHG emissions (CO_2e/ha)	1447		1198	
CH_4 (%)	78,5		77,0	
N_2O (%)	19,1		19,4	
CO_2 (%)	1,7		2,6	
Meat emissions (kg CO_2e/kg meat)	15,7		11,5	
Wool emissions (kg CO_2e/kg wool)	20		19	
Fossil energy use (MJ/kg meat)	7,9		3,5	
	N	P	N	P
Nutrient balance (kg/ha)	9,2	-0,23	9,6	-0,66
Nutrient losses (kg/ha)	10,6 (*)	0,52 (**)	8,2	0,53

(*) _ For N is leaching and gaseous losses, (**) _For P is runoff

In the case of energy intensity, there was an improvement in the energy use efficiency and a reduction in the use of non-renewable fossil energy, explained by the decrease in the use of imported supplements, with their associated embodied energy and the higher production of meat per hectare. There was a significant reduction in total GHG emissions/ha, caused by the reduced stocking rate and lower environmental embodied emissions from the inputs due to less use of the supplement (emission from transport and processing). The outstanding result is that together with the increase recorded in meat production/ha (29%), there was a reduction in the emissions intensity by more than 40%.

In the case of nutrient balance, there is evidence of low N and P inputs, outputs (in meat & wool), however in case of P the results indicate some mining of P which could slowly deplete fertility.

3.2 Model discussion

This model was developed as a decision support system to be used for cattle and sheep farmers and advisors as an indication of their resource use and environmental emissions. The focus of the model is on providing an estimate of on-farm potential environmental impacts based on farm-specific inputs and outputs. Although EMAG provides a holistic approach to farm-scale assessment of the effect of management practices on farm-average environmental losses, it has the constraint that it does not provide environmental information specifically for the individual blocks within the farm. However, the model has the ability to account for differences in land use, inputs, production and management between blocks within the farm.

The model considers feed data from diverse types of land and feed resources used for cattle and sheep production. It accounts for different type of pastures (e.g. natural pastures from different regions of the country, mix of forage species or legume oversown in natural pastures) and a wide range of supplementary feeds. If the user is lacking some specific feed information for the farm system, the model has default values that can be selected. Where natural pasture represents the major resource used for feeding animals, the quantity and quality of information is a key aspect which is particularly important for Uruguay. Therefore, the model provides options for using pasture production estimated from national research information from different regions, or dry matter production from satellite monitoring. This information is provided by the IPA through the LART project[48]. The system uses satellite information translated into forage production taking into account different types of pasture, weather conditions and eco-physiological factors[49]. Pasture quality information is more difficult to determine, especially considering changes between seasons, and default average values can be selected. However, in all cases this is likely to be underestimated because animal selection during grazing probably results in higher quality values for actual intake[50].

EMAG produces a range of production and environmental indicators. Both are connected through the calculation of environmental intensity indicators, for example, for GHG emissions per kg of meat exported from the system. This requires that the model calculates production indices based on the animal input information that the user provides on an annual basis. However, when the user wants to develop scenarios through implementation of technologies, they need to make an assumption about the likely impact on production in the model.

Methane emissions represent the greatest contributor to whole GHG emissions from cattle systems, representing about 75%[6], and the emission intensity by product is higher for extensive systems than intensive systems[51]. The majority is provided from enteric fermentation and is relatively high due to low digestibility of natural pasture during the year than for introduced pastures. Digestibility affects the calculated intake value, which has a large effect on enteric methane emission and can have a significant effect on the total system GHG emissions. Methane emissions from dung during grazing is included[17], but the contribution to overall methane production is minor.

Related to the GHG indicator, the model currently ignores C sinks and the contribution of changes in on-farm C stocks (soil, pasture, or forest on farm) to on-farm GHG emissions. However, international agreement on how to account for some of this is lacking. Embodied CO_2 emissions and fossil energy demand from the production of inputs were included in the model to indicate the impacts from all the input emissions linked to farm production and on-farm activities. The values for these embodied emissions are now based on relatively old data[20]. Although updated values are not available, it is probable that modernization and efficiency gains within the processing industry would suggest that the values used are probably overestimating the processing contribution.

In the case of natural N inputs as atmospheric deposition, the model uses the unique information provided from national research[23]. This is important since it is often the main N input in animal systems (e.g. breeding systems) in Uruguay, where the main forage resource is natural pastures and where commonly no mineral fertilizer is applied, and the very low percentage of natural legume determines low N fixation. There is a possible minor contribution of N_2 fixation from free-living microorganisms, however following LEAP guideline to not be included in accounting for N flows unless published local data are available. This has a relatively large effect on the calculated N balance, as shown in the case farm study. This study also showed a small negative P balance, suggesting that the farm is mining its soil P reserves. However, there is uncertainty around the P index in the model that is used to estimate P losses from the system. More research is needed to provide better data for more accurate calculation of P losses and the P balance in the future. In the model, a key input that the user needs to provide is P content in the soil, which is not easy to obtain and could change between blocks with different management.

EMAG provides environmental emissions results on a per-hectare basis —which is particularly relevant for nutrient losses to water— as well as on a per-kg product basis. The latter is useful for producers/processors/marketers. For the nutrient balance, the tool is valuable to identify whether a system is mining soil P and/or N as an indication of long-term sustainability. Similarly, the fossil energy use efficiency provides a guide to level of depletion of a key non-renewable resource.

In summary, EMAG provides a holistic approach to farm-scale assessment of the effect of management practices on environmental losses. It is an evolving model, with ongoing improvement in output predictions and addition of new mitigation options as more research is generated. For example, it is possible to include indicators of other resource use (including for off-farm land, such as where you have cattle supplementation with brought-in feeds) or pesticide use.

4. Conclusion

Cattle and sheep systems in Uruguay and worldwide are challenged to reduce their environmental footprint while increasing efficiency and production.

To achieve this challenge, user-friendly tools are needed that can translate research findings into practical information that could improve decision making by farmers and advise different stakeholders. EMAG is an innovative "Uruguay-specific" model that can provide information for the national cattle and sheep sectors to quantity key indicators of importance at global and local scales.

This model meets the current methodology requirements according to international guidelines(11)(12)(52) to evaluate environment emissions. It could be used to assist the national cattle and sheep sector to be aligned to Uruguayan international commitments and markets. However, Uruguay still needs to continue working and evolving its farm systems toward the implementation of sustainable practices, and EMAG could be a support for achieving this.

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Author contribution statement

GB wrote the paper, conceived and designed the analysis, collected the data, development of the tool and performed the analysis, discussion of results, and conclusions.

SL contributed to writing the paper, the development of the tool, and performed the analysis and discussion of results.

LA contributed to writing the paper.

CL contributed to writing the paper, development of the tool, and performed the analysis and discussion of results.

FD contributed to writing the paper and development of the tool.

HM contributed to writing paper, the discussion of results and the conclusions.

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Supplementary material

Supplementary table S1. Model output comparison for NZ hill farm systems.

	EMAG (UY)	OVERSEER (NZ)
Live-weight sold kg/ha	345	317
Energy use MJ/kg LW	4.7	4.3
N surplus (kg N/ha/yr)	51	49
P surplus (kg P/ha/yr)	10	11
N leaching (kg N/ha/yr)	18	13
GHG (kg/ha/yr)	3989	3559
Carbon footprint (kg CO_2e/kgLW)	11.6	11.2

Supplementary table S2. Model output comparison for Canadian farm system.

	EMAG (UY)	Canada data	OVERSEER (NZ)
Live-weight sold kg/ha	27	~30	46
Energy use MJ/kg LW	28		20
N surplus (kg N/ha/yr)	12		12
P surplus (kg P/ha/yr)	1.0		<1
N leaching (kg N/ha/yr)	0.4		0.9
GHG (kg/ha/yr)	330	334	336
Carbon footprint (kg CO_2e/kgLW)	13.3	13.0	12.9