Agriculture, Ecosystems and Environment 240 (2017) 135–147

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change

Sarah J. Gerssen-Gondelach[a,*], Rachel B.G. Lauwerijssen[a], Petr Havlík[b], Mario Herrero[c], Hugo Valin[b], Andre P.C. Faaij[d], Birka Wicke[a]

[a] Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] International Institute for Applied Systems Analysis (IIASA), Ecosystems Services and Management Program (ESM), Schlossplatz 1, A-2361 Laxenburg, Austria
[c] Commonwealth Scientific and Industrial Research Organisation (CSIRO), 306 Carmody Road, St Lucia, QLD 4067, Australia
[d] Energy and Sustainability Research Institute, University of Groningen, Nijenborg 4, 9747 AC Groningen, The Netherlands

A R T I C L E I N F O

Article history:
Received 27 May 2016
Received in revised form 17 January 2017
Accepted 12 February 2017
Available online xxx

Keywords:
Livestock production
Production systems
System transitions
Incremental and transformational system changes
Climate change mitigation
Cradle to farm gate emissions

A B S T R A C T

Cattle production is characterized by high land requirements, and greenhouse gas (GHG) emissions associated with the resulting land use change (LUC) and cradle to farm gate processes. Intensification of cattle production systems is considered an important strategy for mitigating anthropogenic GHG emissions. When categorizing production practices into three systems, i.e. pasture-based, mixed and industrial systems, intensification can either take place within one system or through the transition to another more productive system. This study investigates the impacts of these two pathways on farm gate emissions and LUC-related emissions (expressed in kg CO_2-eq per kg of milk or beef) in nine world regions. First, a review is conducted of bottom-up studies on farm gate emissions (without LUC) from dairy production in Europe and beef production in North America and Brazil. Then, a global data set on GHG emissions from cattle production is used to discuss the GHG emission impacts of the two development pathways in other regions. Finally, the GLOBIOM model is applied to perform a global assessment of land occupation and LUC-related emissions. For dairy in Europe, farm gate emission reductions of 1%–14% are found for intensification within one system and 2%–26% for system transitions. In Europe as well as other developed regions, the comparative influence of both pathways on the GHG balance largely depends on the specific design of the initial and final production systems. In developing countries especially, there is a greater potential for emission reductions through intensification within the pasture-based system. The additional reduction potential of moving from pasture-based to mixed and industrial production is limited. Also, emission reductions of intensification within the mixed system are smaller compared to the pasture-based system. For beef production in Brazil, intensification within pasture-based systems can attain significant farm gate emission reductions (>50%). The same is true for pasture-based systems in other developing regions and also some developed regions. Furthermore, the additional GHG reduction potentials of moving from pasture-based to mixed systems, and of intensification within mixed systems are larger for beef than for dairy. Although both the dairy and beef sector can often attain significant farm gate emission reductions through intensification within pasture-based systems, the transition to mixed systems is important to reduce land occupation and LUC-related emissions. LUC mitigation is considered to be the most important GHG mitigation strategy for cattle production in Sub-Saharan Africa and Latin America. Important, but technically and economically constrained strategies to reduce both farm gate and LUC-related emissions include increasing the productivity of grassland and cropland, and increasing the animal productivity through improved feed quality.

1. Introduction

The livestock sector is an important user of natural resources and has significant influence on local landscapes and ecosystems (Herrero et al., 2011; McMichael et al., 2007; Phillips et al., 2006).

* Corresponding author.
E-mail addresses: sjgerssengondelach@gmail.com (S.J. Gerssen-Gondelach), r.lauwerijssen@live.nl (R.B.G. Lauwerijssen), havlikpt@iiasa.ac.at (P. Havlík), mario.herrero@csiro.au (M. Herrero), valin@iiasa.ac.at (H. Valin), a.p.c.faaij@rug.nl (A.P.C. Faaij), b.wicke@uu.nl (B. Wicke).

http://dx.doi.org/10.1016/j.agee.2017.02.012
0167-8809/

This sector is responsible for approximately 15% of the global greenhouse gas (GHG) emissions and is therefore one of the main contributors to climate change (Bellarby et al., 2013; Gerber et al., 2013). In addition, the land required for livestock production, both direct for grazing and indirect for feed crop cultivation, accounts for 70% of the global agricultural land area and covers up to 30% of the ice-free terrestrial surface of the planet (Steinfeld et al., 2006a). The impact on GHG emissions and land occupation is especially large for cattle production, which accounts for an estimated 65% (Gerber et al., 2013) or even 77% (Herrero et al., 2013) of the total livestock-related GHG emissions. Also, land use change (LUC) related emissions can make up a significant share of the GHG balance of cattle production (Havlík et al., 2014).

While current emissions are large, there is a significant potential to reduce the GHG impacts from dairy and beef production. For example, Gerber et al. (2013) estimate that the livestock sector emissions can be reduced by approximately 30%. About 65% of these reductions can be attained in the cattle sector. To reduce emissions, numerous GHG mitigation options are suggested (e.g. Eckard et al., 2010; Hristov et al., 2013; Smith et al., 2008). Such mitigation strategies are often related to intensification of cattle production. Intensification can be realized by, for example, fertilizing pastures to enhance the pasture productivity, reducing the grazing period and adding more concentrated (less fibrous) feed to the diet (Eckard et al., 2010; Hristov et al., 2013; Smith et al., 2008). As a result of improved feed quality (feed digestibility), the intensity of methane emissions (per kg of beef or milk) from enteric fermentation declines (Herrero et al., 2013). Higher feed quality also increases animal productivity (quantity of milk or beef produced per animal), which leads to a further decline of the non-CO_2 emission intensity. However, the housing of animals, production of feed crops and use of fertilizers may increase the emissions from manure management, feed production and energy use, and partially counteract the direct cattle emission reductions from intensification.

To study global livestock production, production practices are generally categorized into three well-contrasted systems, i.e. pasture-based, mixed and industrial systems (Robinson et al., 2011; Seré et al., 1996). When using this system classification in the context of intensification in the cattle sector, a distinction can be made between (i) intensification within one system and (ii) transitions from one system to a more efficient and productive system (i.e. from pasture-based to mixed and from mixed to industrial). Due to the clear distinction between the systems, these two pathways imply different natures of change. While intensification within one system is characterized by incremental change, a system transition involves transformational change. Therefore, it is expected that these two development pathways will have different impacts on the GHG balance and land occupation. However, this has not been investigated yet in a systematic way. Although a large number of studies has investigated the GHG performance of dairy and beef production systems, and to a lesser extent also the potential of GHG mitigation options (Havlík et al., 2014; Schader et al., 2014), they lack a clear comparison of the effects of the two development pathways. In addition, has not been assessed how the impacts differ between regions. Better insight in these aspects is valuable for designing strategies and policies for future sustainable development of the cattle sector. Therefore, the aim of this study is to compare the GHG emission impacts of intensification within one system and of system transitions. This is done for three indicators: cradle to farm gate GHG emissions, land occupation and LUC-related emissions. The assessment considers both dairy and beef production in nine world regions, based on results from studies in the literature and on data and simulations from the Global Biosphere Management Model (GLOBIOM).

The remainder of this paper is structured as follows: Section 2 describes our approach, the production systems considered, and the impact categories selected to assess the effects of intensification. Section 3 discusses the respective impacts of each development pathway on GHG emissions without LUC, land occupation and LUC-related emissions, and compares the impacts of the two pathways in each region. Section 4 offers a discussion, and conclusions are drawn in Section 5.

2. Materials and methods

2.1. Selection of literature data

For the assessment, literature studies were collected that conduct analyses of the GHG impacts and land requirements of dairy or beef production systems in specific regions, based on bottom-up data. Each study was selected based on the use of similar system boundaries and emission sources, the availability of data on the total milk or beef production, and the ability to convert the results to the functional unit used in the present study (see Section 2.3). In total, 72 studies on dairy production (from 31 publications) and 47 studies on beef production (from 17 publications) were found. The majority of the studies was published in 2009 or later and assessed production systems that represent typical systems in the considered region. Therefore, the studies are considered to provide a good representation of current production practices in the regions covered. The majority of studies are based on modeling exercises instead of actual experiments. Still 22 studies on dairy production (from 11 publications) and 24 studies on beef production (from 7 publications) are based on actual experiments. A detailed overview of all studies, including their main specifications and results, is provided in the Supplementary material (S1–S4).

Table 1 gives an overview of the number of studies per region and shows that the different world regions are not equally covered. Therefore, the dataset from Herrero et al. (2013) is used to discuss the GHG emission impacts of the two development pathways in regions that are poorly covered by the literature. This dataset provides a consistent picture of, for example, feed use, feed conversion efficiency and non-CO_2 GHG emissions for cattle production in 30 regions (see table S7 in the Supplementary

Table 1
Number of studies on GHG emissions from dairy and beef cattle by region and production system. An overview of the studies included in this review and their main characteristics is provided in the Supplementary material (S1 and S2).

Production system	Europe		Asia[a]		Africa[a]		North America		Latin America and the Caribbean[b]		Oceania		Total	
	Dairy	Beef	Dairy	Beef	Dairy	Beef	Dairy	Beef	Dairy	Beef	Dairy	Beef	Dairy	Beef
Pasture-based	17	2						1	2	10	2	4	21	17
Mixed	26	17					4	7	2	0	3	4	35	28
Industrial	6			1			9	1	1				16	2
Total	49	19	0	1	0	0	13	9	5	10	5	8	72	47

[a] When considering nine world regions in this study, Asia is divided into three world regions and Africa is divided into two world regions (Herrero et al., 2013).
[b] In the rest of the article, this region will be referred to as Latin America.