POSITION PAPER

Farm-level digital monitoring of greenhouse gas emissions from livestock systems could facilitate control, optimisation and labelling

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1 Greenhouse gas emissions from livestock

Societal efforts to limit climate change necessitate the participation of all major emitters. Global livestock production of both ruminant and non-ruminant animals contributes annually about 7.1 Gt CO_2-eq (14.5 %) of anthropogenic greenhouse gas (GHG) emissions (Gerber et al., 2013). Unfortunately, diffuse non-point sources make accurate monitoring systems expensive and prevent an efficient implementation of emission regulations in both the crop and livestock sectors. Proposed remedies include subsidies and taxes on management regimes, which are correlated with emissions. The available farm-level GHG calculators comprise automated web-, Excel-, or other software-based calculation tools, which rely on coarse approaches used in national GHG inventories (e.g. IPCC Tier 1 and 2 GHG emission factors) and are therefore too simplistic to depict farm-level emission fluxes in sufficient detail (Denef et al., 2012).

GHG emissions from livestock systems involve up to four distinct categories (*Figure 1*). Firstly, machinery used for land management, operation of livestock facilities, and transportation and processing of livestock commodities requires fuel and electrical power. Also fertilisers, pesticides, buildings, and machinery contain embedded energy. Emissions from fuel and power use are generally easy to monitor because most energy is accounted at power meters or fuel nozzles, whereas embedded energy is more difficult to define and would need agreed tabulated values to enable selection options for famers.

Secondly, enteric fermentation from ruminant animals causes methane emissions. The magnitude of these emissions depends on the breed of animal, feeding regime, and various operational and environmental factors (Hristov et al., 2018). Thirdly, livestock manure leads to methane and nitrous oxide emissions. The breed of livestock, diet, manure storage and handling, and environmental factors affect emission levels (Chadwick et al., 2011). Respiration chambers are the state-of-the-art measuring method for emissions from both enteric fermentation and manure.

Fourthly, carbon dioxide, methane, and nitrous oxide are emitted on pastures and livestock-related croplands. These emissions vary highly across local soil and weather conditions and land management regimes. Vegetation composition, stocking density, applications of manure, mineral fertilisers, and pesticides, and intensity of irrigation affect emissions also on pastures (Bolan et al., 2004). Emissions from croplands are further impacted by the choice of crop rotation and soil tillage.

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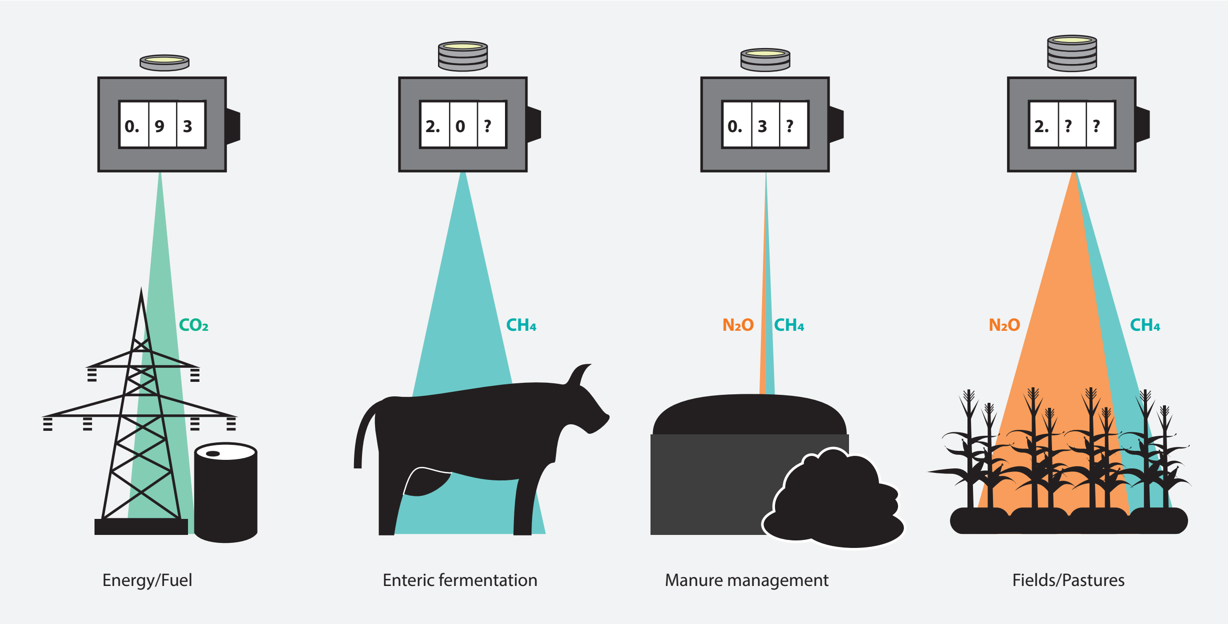

FIGURE 1
Total GHG emissions from livestock systems in 2016 according to FAOSTAT. Values in upper boxes show the global contribution in Gt CO_2-eq. The number of question marks symbolises the variability of emissions. Coin piles depict qualitative differences in measurement costs.

2 Digital monitoring of livestock emissions – Linking detailed farm records and scientific models

Current market transactions can account for on-farm and off-farm emissions from livestock-related energy combustion. However, effective and efficient emission regulations require a comprehensive and accurate accounting of all significant on-farm emission sources and sinks from livestock. To quantify emissions from enteric fermentation, manure and land management, we propose a digital monitoring network where state-of-the-art scientific models take over the tasks of expensive measurement devices or simplistic accounting tools. The digital monitoring network would control information exchange and information processing between farmers, IT enterprises, authorities, scientists, and the public (*Figure 2*).

One network component is a suite of scientific tools supported by scientists for the estimation of on-farm emissions that are difficult to measure. These tools depict agro-ecological processes and estimate emissions from i) enteric fermentation of ruminant animals, ii) manure management, and iii) management of pastures and croplands used for feed production. Emissions from enteric fermentation and manure management can be predicted using detailed empirical or mechanistic models (Rotz, 2018). The latter depict nutrient digestion, absorption, microbial development, and fermentation stoichiometry to determine methane emissions. An important determinant for the accuracy of these predictions is the quality of input data, i.e. data on feed intake and composition, body weight and movement, housing and manure handling and, in the case of dairy, milk yield. Predictions of emissions from pastures and croplands are more challenging. However, over the past decades agricultural scientists have developed ever more detailed biophysical process models to simulate cultivated vegetation on agricultural fields under specific soil and weather regimes (Brilli et al., 2017). State-of-the-art crop models include EPIC (Wang et al., 2012), DayCent (Del Grosso et al., 2005), DSSAT (Jones et al., 2003) and several others. These models operate on a daily time scale and depict all major interactions between vegetation, soil, weather, and land management. Simulated environmental impacts include soil organic matter changes, emissions of trace gases, soil erosion, nutrient leaching, and others. Supported by scientific experiments in many diverse case studies, the representation of relevant biophysical processes has reached a mature stage. Nevertheless, the quality of local model predictions depends strongly on the quality of input data.

A second component of our proposed digital monitoring network consists of livestock farmers. Participating farmers would record and submit detailed information on the number and characteristics of animals, animal feeding and product yields, manure management and date, location, and intensity (e.g. ploughing depth, seed density and fertiliser type and application rate) of pasture and cropland operations. Some or eventually all of this information could be automatically collected through digital devices. Farmers using computerised feeding systems or sensor and satellite supported fertiliser applications could automatically submit high-resolution data.

A third network component is a user-friendly IT platform (server), which controls and organises the exchange and processing of information. Farmers can register on this platform and verify the spatial coordinates for their land ownership. Upon registration, the system would examine existing farm data and request amendments if any necessary data are missing, incomplete, or inadequate. Amendments, e.g. for soil data, would mostly require one-time measurements of particular soil properties. The platform would also examine daily meteorological data from the nearest official weather stations, reanalysis data and climate projections. If available, farmers could submit their own meteorological data from approved on-farm weather stations. Registered farmers could provide or link field specific farm management data and receive a prediction of annual emissions in carbon dioxide equivalents per animal or hectare. Farmers could use the system to plan future livestock management and predict productivities and emissions. The IT platform could be soft or hard linked to existing farm management tools already used by farmers.

A fourth component involves governmental authorities and regulations. Authorities could use the system to verify GHG balances of participating livestock producers. The more farmers who register and participate, the more information about livestock impacts would be available on aggregate regional, national, or even international scales. Authorities could use this information to better plan, design, or amend policies. The fourth component would also include the implementation of data privacy laws to protect non-public data.

Finally, a fifth component addresses specific interest groups and the public. They would be able to access aggregate information, to inform themselves, to play scenarios, and to participate in public debates. A possible application would be the estimation of detailed environmental footprints for crop and livestock commodities.

The proposed digital emission monitoring system would improve emission accounting from crop and livestock production and allow a more efficient regulation of these emissions. Despite public benefits from reduced environmental externalities, there is a question of private cost and benefits. Why should farmers voluntarily register and participate in a digital emission accounting system, spend effort on organising information, and risk adverse consequences from disclosing detailed business information? Firstly, if farmers subjected to climate policies refused to use accurate emission accounting methods, they or the authorities would employ inferior methods, e.g. assign default emission factors. The submission of such more biased or more uncertain emission estimates should result in financial disincentives based on society's risk aversion preferences (Kim et al., 2008). If, on the other hand, farmers did use a detailed and accepted accounting method, they could legally verify their actual emission values and pay fewer emission penalties or, in case of negative emissions, gain higher rewards. Additional benefits from participation include enhanced planning tools for farm management, computation of various environmental footprints, and access to commodity labels.

3 Conclusions

GHG emissions from crop and livestock production are highly variable across fields and animals. Traditional options for accounting and regulating GHG emissions from agricultural operations are either costly or imprecise. Most existing policy proposals include practice-based payment systems with a fairly large uncertainty. We suggest an emission-based payment system with a digital monitoring network, where validated state-of-the-art scientific models eliminate the need

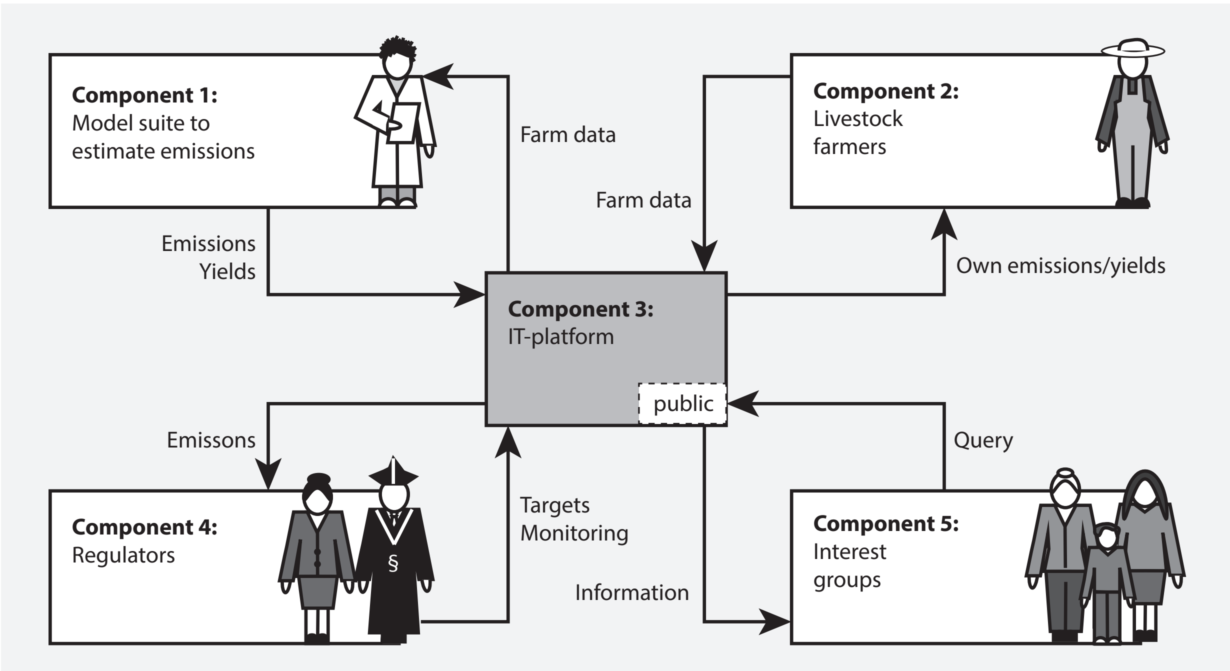

FIGURE 2
Integrated digital emission monitoring system

for costly measurement devices. This network would be applicable to all agricultural operations including specialised crop or livestock businesses and mixed farms.

Emission measurements would still be needed for model validation, however, only at certain intervals on selected sites. Suitable models are already used in scientific assessments and for national GHG inventories. However, the often low quality of input data severely limits the quality of model-based assessments. We therefore propose to combine sophisticated scientific models with detailed and comprehensive management information available at farm level. The reduced uncertainty of otherwise crudely estimated emissions should translate into a financial incentive for farmers to participate. The increasing digitalisation of agricultural operations could facilitate automatic or semi-automatic exchange of data between farmers, scientific tools, authorities, and the public.

The complex modelling system would also permit monitoring of agro-environmental impacts beyond greenhouse gases, including nutrient and pesticide leakages to water bodies and soil erosion. Participating farmers could also benefit from access to new market labels based on ecological footprints rather than on a crude distinction between organic and conventional agriculture.

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