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Carbon footprint of China's livestock system – a case study of farm survey in Sichuan province, China

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A B S T R A C T

Characterizing and quantifying the carbon footprint (CF) of livestock production would offer insights into how livestock production contributes to climate change and help to establish potential greenhouse gas (GHG) mitigation options. In Sichuan, one of the largest provinces for livestock production in China, a questionnaire farm survey was performed in 2012. CFs of livestock and poultry production were quantified using a dataset encompassing 20 farms for egg production, 25 farms for milk production, 20 farms for chicken production, and 32 farms for pork production, including both household and aggregated farms. The results revealed that over both farm types, emissions from manure treatment accounted for 70% and 74% of the total CFs in egg and chicken production, respectively. On average, 39% of the total CF in milk production was contributed by enteric fermentation; meanwhile, emissions by fodder production contributed on average 75% to the total CF of pork production. In general, egg, milk, chicken and pork production in Sichuan were associated with CFs of 3.70, 1.01, 20.02 and 5.42 kg CO_2-eq/kg production for household farms, and 3.46, 1.13, 7.86 and 4.29 kg CO_2-eq/kg for aggregated farm, respectively. Statistically, egg, chicken and pork production on household farms was characterized by higher CFs than that on aggregated farms. This study highlights that aggregated farm management could be an efficient option to mitigate the GHG emission in China's livestock production.

1. Introduction

Environmental issues and food security are common human concerns as a result of global climate change. Nowadays, population explosion and the resulted growing demand for resources intensify food and energy crises, and also attract increasing attentions (Steinfeld et al., 2006; FAO, 2009; Godfray et al., 2010). As the largest current emitters of anthropogenic greenhouse gas (GHG), China contributed 21.18% of global GHGs emissions (Wang et al., 2014). Furthermore, GHG emissions from agriculture in China have been estimated at 819.97 Tg CO_2 equivalents (CO_2-eq), accounting for 10.97% of the nation's total emissions in 2005 (NDRC, 2012). According to the “U.S.–China Joint Announcement on Climate Change” distributed in November in 2014, China will achieve the peak of CO_2 emissions around 2030 and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030 (Xinhua net, 2014). Thus, the concerns about reducing GHG emissions to mitigate climate change have recently provoked the assessment of so-called carbon footprint (CF) for various activities and products.

The assessment of CF has been widely applied to industrial production, agricultural productions, transportation, household activities as well as social activities (Wiedemann and Minx, 2008; Finkbeiner, 2009; Kenny and Gray, 2009; Dubey and Lal, 2009; Franz and Adrian, 2012; Gan et al., 2014). In general, the recent studies focused on general features of agricultural CF, including crop production as well as livestock and poultry production primarily at regional or state scale (Cheng et al., 2011, 2015; Gan et al., 2014). A bulk CF of China's crop production was estimated at 2.86 t CO_2-eq/ha/yr, in which N fertilizer induced GHG emissions made a 65% contribution (Cheng et al., 2011). In a recent calculation, the average CFs of beef, sheep and goat meat, pork, poultry meat, eggs and cow milk productions in the EU-27 were given with 22, 20, 7.5, 5, 3 and 1.4 kg CO_2-eq per kg product, respectively (JRC, 2010). Edwards et al. (2009) reported that lamb and beef had the CFs of 8.1–31.7 and 9.7–38.1 kg CO_2-eq/kg live weight under conventional farm system in Wales, UK.

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China's livestock production ranks first in the world, and the output of meat, milk and egg livestock products in China increased from 45.84, 7.36, 19.65 million tons in 1996 to 83.87, 38.75, 28.61 million tons in 2012, respectively (NBS, 2013). GHG emissions from animal enteric fermentation and manure management have been estimated at 445 Tg CO_2-eq, accounting for 45.7% of the nation's total agricultural emissions in 2005 (NDRC, 2012). Thus, livestock and poultry production in China plays a significant role in global climate change. However, assessment of CF of China's livestock and poultry production has not yet been available though there has been some information of GHG costs associated with N_2O and CH_4 emissions in livestock and poultry production (Dong et al., 2008; Vergé et al., 2009). To identify the contributions of livestock and poultry production to climate change and key mitigation options, quantifying and assessing the CF in China's livestock and poultry production is urgently required.

According to statistics, Sichuan province is one of the largest livestock producers in China with the output of pork, poultry, eggs and milk being 4.964, 0.93, 1.464 and 0.7118 million tons, respectively. Hu and Wang (2010) reported that most of GHG emission by livestock and poultry production occurred in Sichuan province during the period of 2000–2007. Therefore, Sichuan province was chosen to conduct this case study on CF estimations of egg, milk, chicken and pork system. The main purposes of the study are to (i) quantify the CFs of the livestock and poultry system, (ii) identify the contributions of individual GHG sources to total CF, (iii) investigate the difference of CFs between household and aggregated farming management systems. Finally, GHG mitigation potentials and key measures based on CF reductions were also discussed.

2. Materials and methods

2.1. Carbon footprint, functional unit and system boundary

CF of livestock and poultry system was generally evaluated by taking into account all the GHGs emissions caused by or associated with material used, farm management and power exhausted for livestock and poultry production. GHG refers to the three main GHG of CO_2, N_2O and CH_4. CF calculated in this study was expressed in carbon dioxide equivalent (CO_2-eq) per unit livestock or poultry production.

Functional Unit The functional unit for this CF study was 1 kg CO_2-eq/kg of pork (LW)/milk/chicken/egg (LW). LW: Live weight.

Goal A life cycle assessment was employed to describe the total GHG emissions including CO_2 (1), CH_4 (25) and N_2O (298) (IPCC, 2007) by pork, milk, chicken and egg production in Sichuan province of China. On the basis of this analysis, various aspects of livestock or poultry system of GHG emissions were determined.

System boundary “Cradle-to-farm gate” was set as the system boundary in this study, which was shown schematically in Fig. 1.

Scope The scope was a life cycle of livestock and poultry from feed crop production to livestock and poultry production harvest (Fig. 1). In this study, there are three stages during the production of livestock and poultry, which including feed production process, animal production process and waste handling and treatment process. The calculation includes two important components. One is the GHG emissions of production of inputs, which included labor, chemical processes, mechanical processes and use of gasoline. The second one is the GHG emissions of livestock or poultry system, which includes the emission of CH_4 by enteric fermentation, and of N_2O and CH_4 from the process of manure treatment. The scope of this analysis does not include the slaughtering, processing and packaging, transportation of livestock and poultry products. Infrastructure elements, such as construction of buildings and farm equipment, were also excluded.

2.2. Sources of emission and calculation

2.2.1. Forage input

According to the field survey conducted in this study, the types of forage include: (i) mixed forage (corn (67%), soybean flour (19%) and wheat bran (14%)), self-made forage (corn (60%), bran (30%) and concentrates (10%)) and green forage (sweet potato vine) for pigs; (ii) concentrated forage for layers with the mix of corn (65%), soybean flour (15%), wheat bran (10%) and feed additives (10%); (iii) concentrated forage for broilers with the mix of corn (70%), soybean flour (20%) and wheat bran (10%); (iv) concentrated forage for dairy cows with the mix of corn (55%), soybean flour (25%) and wheat bran (20%).

The GHG emissions from forage input include crop cultivation, forage processing and forage transportation. In general, carbon cost of forage input (CF_{forage}, kg CO_2-eq) was estimated using the following equation:

$$CF_{forage} = \sum CF_{C,i} + \sum CF_{P,i} + \sum CF_{T,i} \quad (1)$$

Where, $CF_{C,i}$, $CF_{P,i}$ and $CF_{T,i}$ denotes the GHG emissions (kg CO_2-eq) induced by crop cultivation, forage processing and forage transportation for forage type i, respectively. $CF_{T,i}$ was calculated by multiplying the amount of fuel consumption (kg) by emission factor of fuel (EF_F). The CFs of various crop productions and forage processing used in this study were shown in Table S1 and S2.

2.2.2. Farm management

The GHG emissions induced by farm management (CF_M, kg CO_2-eq) were calculated using the following equation:

$$CF_M = F \times EF_F + E \times EF_E + L \times EF_L \quad (2)$$

Where, F, E and L denotes the amount respectively of fuel (kg), electricity (kWh) and labor (man-day) used in the life cycle analysis of livestock and poultry system. EF_F, EF_E and EF_L are emission factors respectively of fuel, electricity and labor which were shown in Table S2. Labor use is an important input in agricultural production of China and some developing countries with a large farm population; therefore, the GHG emissions from labor use were calculated according to the previous studies (Li et al., 2009; Chen et al., 2011; Nabavi-Pelesaraei et al., 2014).

2.2.3. Enteric fermentation

The CH_4 emission from enteric fermentation is estimated according to IPCC (2006):

$$CF_{EF} = H \times EF_{EF} \times 25 \quad (3)$$

Where, CF_{EF} is the CH_4 emission (kg CO_2-eq) from enteric fermentation; H denotes the number of ruminant head; EF_{EF} is the emission factors for enteric fermentation (kg CH_4/head/a), which is presented in Table S3; 25 is net global warming potential (GWP) of CH_4 in a 100-year horizon (IPCC, 2007).

2.2.4. Manure treatment

CH_4 and N_2O emission during manure treatment (CF_{manure}, kg CO_2-eq) is estimated respectively using Equation (4) and Equations (5) and (6):

$$CF_{manure} = H \times EF_{CH_4} \times 25 + \left(N_2O_{D(mm)} + N_2O_{G(mm)}\right) \times 298 \quad (4)$$