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DRAFT

Developing climate-smart livestock systems in Inner Mongolia, China

Frank Koslowski[1*], Andreas Wilkes[2], Dominic Moran[1]

1: Department of Land Economy Research Group, Scottish AgriculturalCollege, University of Edinburgh

2: The World Agroforestry Centre (ICRAF), China

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*Corresponding author. Tel.: 0044 (0)7576185511; E-mail address: Frank.Koslowski@sac.ac.uk; Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK.

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Abstract

'Climate-smart' is the term coined to define agricultural systems that are resilient to climate change, and offer efficient emissions mitigation potential without compromising on productivity, food security and livelihoods. As part of the implementation of such systems, this study developed a Marginal Abatement Cost Curve (MACC) for greenhouse gas emission mitigation for a grassland system in Inner Mongolia, China. We identified two baseline emission scenarios and three abatement measures, namely, shorter lambing time, prohibited grazing, and reduced stocking rates. The study region showed a high and cost-efficient abatement potential of 62.5 and 32 Kilotonnes (Kt) of CO_2eq for each baseline, respectively and each Abatement measure lead to cost savings for the herders. Reduced stocking rates provided the largest mitigation potential. Sensitivity analysis showed how increasing input and livestock product prices have consequences for measure adoption.

Keywords China, greenhouse gas, grassland, mitigation, marginal abatement cost curve

JEL code Agriculture: Agricultural Policy; Food Policy Q18

1. Introduction

China has recently overtaken the US as largest source of global greenhouse gas emissions and its growth trajectory suggests that its global share will continue to increase. Specific polluting sectors include energy, transport, manufacturing, and agriculture. Although a non Annex 1 country, China has nevertheless embarked on an ambitious agenda to reduce its emissions at per unit of gross domestic product by at least 40% starting from the 2005 levels until 2020 (Rogelj, 2010). All sectors of the economy are expected to make a contribution to this target and a pilot emissions trading scheme is proposed as a key policy instrument for inducing efficient emissions reductions by 2015 (Linacre *et al*., 2011).

Agricultural activities contribute around 46% of the anthropogenic methane emissions in China. This also includes enteric fermentation (21%) and manure management (2.5%) which correspond to 234.47 Megatonne carbon dioxide equivalent (CO_2eq) by GWP_{100}[1] to around 4% of the CO_2 emissions from fuel combustion, thereby making emission reductions from agriculture a major concern for domestic emissions policy (Zhang and Chen, 2010). Land use management practices are thought to offer considerable scope for emission mitigation in terms of land use change (LUC), grassland management and agricultural practices. Chinese agricultural systems are characterised by a variety of farming practices, implying that mitigation potential is variable and generalisation hazardous. But grassland management offers considerable potential for mitigation measures to be deployed at a large scale, especially in Inner Mongolia where a fairly homogenous system is prevalent, as indicated by governmental restrictions on cultivation, underdeveloped management techniques, and a common cultural background of sheep and goat herders.

This paper considers the scale of cost-effective mitigation potential available in specific grassland areas. Drawing on case study evidence from Inner Mongolia, this paper develops marginal abatement cost curves (MACCs) to define technically effective mitigation measures and to illustrate their relative cost-effectiveness (CE). MACCs are charts that set out the costs of different options for reducing emissions. As an analytical device they are useful for reconciling data on CE of abatement efforts which underpins much of the green growth

[1] The release of greenhouse gases from agriculture is typically expressed in terms of a common Global Warming Potential (GWP) unit of CO_2eq, whereas the GWP of CO_2=1, CH_4=21 (based on a 100-year time horizon), and N_2O=310 (Wassmann and Pathak, 2007).

discourse (Naucler and Enkvist, 2009). The next section describes MACC analysis, and is followed by an application in Siziwang Banner, Inner Mongolia. This includes the description of data on measure costs and technical effectiveness. The results provide the basis of a discussion on the applicability of the MACC approach in a region specific manner.

2. Grasslands in China and Greenhouse Gas (GHG) Mitigation

Grasslands in China cover about 3.98 million km^2, which is equal to 40% of China's total land area, and store approximately 9-16% of the global grassland carbon stocks (Ni, 2002; Akiyama and Kawamura, 2007). Inner Mongolia includes the largest grasslands in China, an approximate area cover of 800,000 km^2. These grasslands have shown continuous degradation for decades, attributed to various factors.

After the 1960s, traditional semi-nomadic grazing disappeared when the government promoted development of large scale communities (Li *et al*., 2007b). Thus, seasonally grazing regimes switched to free grazing throughout the year. Grazing intensity also increased due to population growth, mainly immigration of Han people since the 1970's, thereby leading to over-grazing beyond productive potential (Jiang *et al*., 2006).
Inner Mongolia is also highly vulnerable to wind erosion causing loss of nutrient rich surface soil (Han *et al.*, 2011), with a higher vulnerability on more intensively grazed grasslands (Hoffmann *et al.*, 2008). Furthermore, productivity of the grassland is generally low due to extreme climatic conditions, with a short growing season and a cold winter season from autumn to spring (Kemp *et al*., 2011). Finally, Siziwang Banner is affected by low annual precipitation and high evaporation rates (Han *et al*., 2011).

China is the largest producer and consumer of livestock products, and continuous grassland degradation represents a threat to the livelihoods of 40 million people who belong to the poorest strata of the population (Brown *et al*., 2008). New management techniques and 'climate smart' agriculture are advanced as part of the solution. Climate-smart is the term coined to define agricultural systems that are resilient to climate change, and that offer efficient emissions mitigation potential without compromising productivity, hence food security. This is a form of agricultural multifunctionality, which is also focussed on the need for rural poverty alleviation, (Meridian Institute, 2011). In Inner Mongolia, it is thought that significant potential lies in measures related to soil carbon and livestock management. These abatement measures (AMs) could also deliver significant level of cost-efficient abatement potential.

Emissions from grassland systems are CO_2 and nitrous oxide (N_2O) from soils, which are strongly influenced by the grazing intensity, use of nitrogen based fertilisers and manure utilization (MacLeod *et al*., 2010). Ruminant livestock are a major source of methane (CH_4) emissions from enteric fermentation, and additional CO_2, CH_4, and N_2O through dung, urine, and manure (Lassey, 2008). The volume of GHG emissions depend strongly on feed intake, climatic conditions and animal species.

AMs for soil may include sustainable fertilization methods, controlled grazing, conversion from degraded lands to grasslands, grassland restoration through introduction of improved pastures and sowing of legumes (Lal, 2010). Further measures for livestock include introduction of improved animal species, feed type and modified housing (Hongmin *et al*., 2011). Considering the prevailing conditions in Inner Mongolia, AMs most likely to be implemented focus on those that are generally understood and implementable by herders themselves, and which can be affected by specific regulations. These include reducing grazing pressure and introducing new animal species. Reduced and sustainable grazing intensity tends to improve grassland productivity as well as the carbon sequestration rate, since it affects the vegetation type, organic matter inputs, and soil structure (Piñeiro *et al*., 2010; Smith *et al.,* 2008). The same applies to grazing prohibition, as enclosed grasslands show the fastest improvement in grassland productivity compared to different grazing treatments (Randall *et al*., 2008). The introduction of new animal species is another promising measure as a new species may improve the efficiency per unit product in terms of GHG emissions and rearing costs.

3. MACC Analysis

Governments recognise the need to achieve emissions reductions in an economically efficient manner, and MACC analysis is increasingly used to identify cost-effective mitigation potentials (Moran *et al.*, 2011). A MACC shows a schedule of mitigation measures ordered by their specific costs per unit of CO_2eq abated, where the measures are additional to mitigation activity that would be expected to happen in a 'business as usual' baseline (Figures 1). Some measures can be enacted at a lower unit cost than others, while some are thought to be cost-saving, i.e. farmers could implement some measures that could simultaneously save money and also reduce emissions.[2] Thereafter, the schedule shows unit costs rising until a comparison of the costs relative to the benefits of mitigation show that further mitigation is not worthwhile. A MACC illustrates either a cost-effectiveness or a cost-benefit assessment of measures, where the benefits of avoiding carbon emission damages are expressed by the shadow price of carbon (SPC).

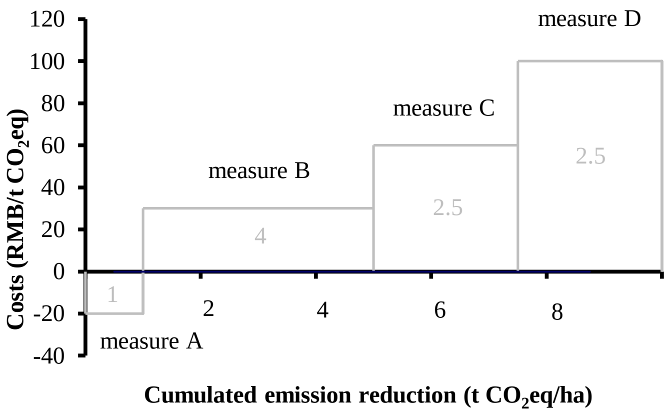


Figure 1: Illustrative MACC including 4 abatement measures with the cumulated and stand-alone abatement potential (t CO_2eq ha^{-1}) illustrated by the horizontal axis and the specific costs per unit of CO_2eq illustrated by the vertical axis.
From left to right, the abatement measures become less cost-effective. Measure A offers cost savings, whereas measures B, C, and D result in additional cost.

MACC variants are broadly characterised as either 'top-down' or ''bottom-up' (De Cara and Jayet, 2011). The 'top-down' variant describes a family of approaches that sometimes uses partial or general equilibrium modelling to share an externally determined emission abatement target to each economic sector, depending on the relative availability of CE measures. Such measures are identified within industrial/commercial sectors according to simplified production functions that are assumed to apply commonly throughout the sector

[2] The fact that some apparently cost-saving measures have not been adopted may be due to a number of reasons, e.g. farmers may not be profit-maximising, or they may be exhibiting risk aversion behaviour in response to fear of yield penalties. Alternatively, farmers may be behaving rationally, but the full costs of the measures have not been captured.

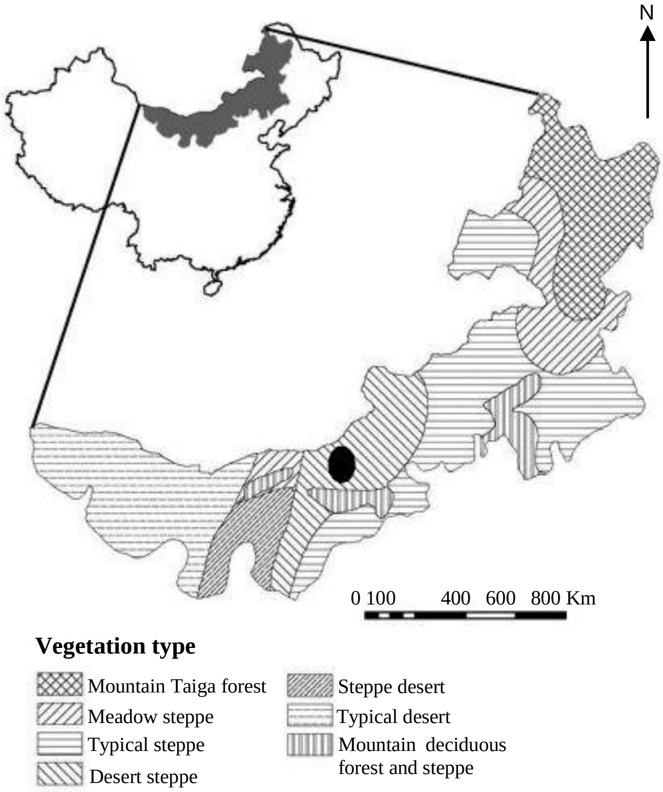
(if not the whole economy). In agriculture, this approach implies substantial homogeneity in abatement technologies; their biophysical potential and implementation costs (see for example De Cara *et al.,* 2005).

A “bottom-up” MACC takes an engineering approach by identifying all potential measures and short listing them depending on their mitigation potential and cost. The CE of individual measure triggers their adoption if they deliver mitigation at a cost less than a carbon price threshold (De Cara and Jayet, 2011). This may be more feasible for agricultural systems as the methods allow heterogeneity in the way measures work in different biophysical environments leading to variability in costs and abatement potential (Moran *et al*., 2011). A bottom-up approach also allows for a consideration of measures that can integrate mitigation and adaption objectives, meaning that measure selection can be more poverty-focused.

A preliminary stage in developing bottom-up analysis is the identification of a baseline scenario, which in this study was the period from 2012 to 2036. This information can be determined through a synthesis of existing policy information, projecting the status and performance of the herders, based on local information as per discussion with scientists from Inner Mongolia Grassland Research Institute (IMGRI). This information also provides the basis for estimating baseline emissions from pre-existing management, and herder revenues, which are compared to the corresponding variables in the mitigation scenarios. Finally baseline and counterfactual (mitigation) scenarios are compared to calculate a cost per unit of CO_2eq. Costs are discounted to reflect measure implementation over the chosen time horizon.

4. Case Study Description

Siziwang Banner is located in the centre of Inner Mongolia Autonomous Region (Figure 2). The total geographical area is 24,414 Km^2 with grazing area of about 85% (Guo *et al.*, 2008; Han *et al*., 2011). Climatic conditions are temperate with an average temperature of 1-6°C (with a long and cold winter period and a short and hot summer period) and a mean annual precipitation of 100-300 mm (Han *et al.*, 2011). The average elevation is 1456 m above mean sea level with predominantly "desert steppe" vegetation. The soil type is mainly calcified steppe, with an organic carbon content of approximately 1.3% (Han *et al*., 2011).



Source: Altered from Han *et al*. (2009)

Figure 2: Location of Inner Mongolia Autonomous Region in the Peoples' Republic of China. Siziwang Banner is indicated by the black ellipse in the enlarged inset map of Inner Mongolia; with geographical coordinates between 110.33° and 113.00°E, and 40.15° and 43.33°N. This inset map also illustrates the different vegetation types, showing that desert steppe is predominant.

The indigenous pastoral community comprises of 6000 herder households with 21,000 people and having a typical farm size of about 400 to 550 hectare (ha) per household. The grassland- based production pattern consists mainly of production of meat, wool and cashmere (Han *et al*., 2011). Common livestock species are the Inner Mongolia Cashmere goat, Inner Mongolia Fat Tail sheep and a hybrid species between the physically well-adapted Inner Mongolia Fat-Tail sheep and the fast growing South-African Dorper sheep. The livestock are freely grazing throughout the whole year. Crop and forage production play a minor role, with utilization of less than one ha per herder (Han *et al.*, 2011). Highest economic returns occur during shearing and lambing months in June and January, respectively (Han *et al.*, 2011). The adult animals are sold in October when animals have attained the largest body weight during the summer season. A certain number of animals are retained in the stock and fed with supplements during the cold winter period. There has been a recent trend of herders joining associations, leading to changes in the production system and higher prices for their products. This is due to the introduction of the hybrid species with shorter gestation periods of just four months, and adults with a 10% higher body weight.

Grassland productivity is relatively low and exacerbated by increasing degradation. Current estimates suggest that 20% of the total grazing area shows low degradation, 60% moderate degradation, and 20% heavy degradation and with about 5% and 4% being affected by desertification and salinisation, respectively (IMGRI, 2011, personal comm.). National government is trying to address the problem through regulations, notably the National Grassland Law can be considered the “flagship” for grassland policies (Brown *et al*., 2011). With a view to promoting lower stocking rates to 0.5 sheep/ha/year, the “livestock and grassland balance management” regulation is the most promising policy element (Zhenyu and Zhang, 2005). The “Return Grazed Land to Grass” program supports the enclosure of degraded grasslands from livestock grazing. While the grassland recovers through exclusion from grazing, herders receive compensation payment of 70 Renminbi (RMB) per ha from the local government. In 2010, 9.6% of the total grazing area was “enclosed” (IMGRI, 2011, personal comm.). The “land reclamation banning” law is aimed at limiting cultivation in grasslands in order to maintain natural vegetation, thus protecting against wind erosion. The law enacts penalties on cultivation with extra taxes and payments from 3000 to 15.000 RMB per ha (IMGRI, 2011, personal comm.).

The precarious livelihoods of the herders mean that mitigation measures cannot be a financial burden. To fit with traditional livelihood strategies, additional measures must be simple and easily implementable, low technology techniques. Management changes are hindered by the fact that herders prize numbers of livestock as a status symbol, trading this off for productivity (Jian-ping *et al*., 2011). Increasing meat demand and rising prices are another pressing issue (Pingali, 2007), leading herders to increase animal numbers. This could be beneficial in the short run, but productivity will decline as soon as the grassland attains a certain carrying-capacity (Randall *et al*., 2008). Therefore, it is important to consider measures that increase the net return for the herders and allow grassland recovery. Accounting for these social, economic and social restrictions this paper predicts two possible baseline scenarios (A1 and A2) over the period 2012 to 2036, onto which three counterfactual measures are applied. Measures applied under these scenarios assume that 80% of the herders will join an association. This assumption is derived from expert judgement by scientists of Inner Mongolia Agricultural University, IMAU. Baseline scenario A1 defines a reduction to a moderate grazing intensity (MGI) of 0.5 head/ha /year as per adoption of the livestock and grassland balance management regulation. Baseline scenario A2 assumes conditions similar to the year 2010, showing a heavy grazing intensity (HGI) and a prohibited grazing area of 9.6%.

The AMs are defined as follows - Shorter lambing time implies a lambing time of four months, which is similar to an overall introduction of the stated hybrid species. Prohibited grazing, assumes that 30% of the total area could be enclosed (IMAU, 2011, personal comm.). Such enclosure would not be implemented by government regulation and thus no compensation payments are made. A reduced stocking rate scenario allows a low grazing intensity (LGI) of 0.3 head/ha /year which was assumed to be a sustainable stocking rate.

4.1. Abatement potential in soil and livestock

4.1.1. Soil carbon

Li *et al*. (2007a) reported the organic carbon content in soils at 20 cm depth in enclosed areas, under LGI, MGI and HGI, in Siziwang Banner, at the rates of 35.56 t/ha, 35.86 t/ha, 29.64 t/ha, and 32.38 t/ha, respectively. The soil carbon sequestration rate under grazing enclosure in northern China requires 25 years until soil saturation (Wang *et al*., 2011). This study adopts a similar time horizon for different grazing treatments. N_2O emissions are not counted as fertiliser usage is an uncommon practice and only a minor area was cropped. Estimates of the total carbon sequestered for each scenario is derived by multiplying the grazed area at a certain grazing intensity by the corresponding carbon content, and similarly for the area enclosed from grazing if necessary (and added together), for the baseline scenarios and abatement scenarios separately. Organic carbon is converted to CO_2eq using a factor of $\frac{44}{12}$ from IPCC (2006).

4.1.2. Livestock emissions

Livestock emissions factors were based on the following feed regimes: i) fresh grass, referring to feeding only through grazing mainly during the period from June to August, and ii) hay concentrate mix in a ratio of 75:25 mainly during the period from September to May when sheep are fed with supplements (Wang *et al.*, 2009; 2007). The share of concentrate may be higher within different scenarios and especially during winter, but a lack of data prevents the estimation of emissions for this scenario. Jiang *et al.* (2012) reported CH_4 and CO_2 fluxes from sheep urine and dung patches in a desert steppe and concluded that these patches were a negligible source of CH_4, but strongly increased CO_2 emission mainly through heterotrophic respiration (Table 1). Hongmin *et al*. (2011) reported CH_4 estimates of 7.1-8.9 Kg/head /year for sheep between 3-7 months. We assume an average CH_4 emission value for lambs, though an estimate for "fresh grass feeding" was not derived, as lambs are fed mainly with supplements in sheds. There is no site-specific data available for emission factors for the hybrid species and Inner Mongolian Cashmere goat and their offspring. Therefore, it was assumed that the CH_4 emissions by ruminant fermentation from the Inner Mongolia Cashmere goat was 26.4% lower as that of the Mongolian Fat Tail sheep, as reported by Shibata and Terada (2010), while for the hybrid species, the CH_4 emissions are taken to be the same (expert judgement by scientists of IMAU; Table 1). Depending on their body weight, the CO_2 emissions from manure were 10% higher for the hybrid species and 10% lower for the Inner Mongolia Cashmere goat (Table 1). Although storage of manure is a common practice in Siziwang Banner, this emission factor was excluded since site specific experimental data are unavailable.

Table 1: Emission factors (Kg /head /year) for different livestock species and their breeds. Based on Jiang *et al*. (2011) and Wang *et al*. (2009; 2007).

Species	**CH_4 by ruminant fermentation**		**CO_2 by excrements**	
	fresh grass	hay concentrate mix	Dung	Urine
Mongolian Fat Tail sheep	5.68	7.08	0.18	1.39
Lamb	2.84	3.54		
Hybrid species	5.68	7.08	0.2	1.53
Lamb	2.84	3.54		
Inner Mongolia Cashmere goat	4.18	5.21	0.16	1.25
Kid	2.09	2.61		

These emission factors need to be applied to specific livestock numbers. The stocking rate and total grazed area per herder within each scenario predicts the total livestock count. Whether or not a herder joined an association predicts which sheep species is being used, the relative share of goats and sheep, the number of produced offspring, and the lambing time. The lifetime of sheep and goats is 5 and 6 years, respectively, meaning that during each year, 20 % of the born lambs and 16.7% of kids will not be sold for replacing the old animals.

Livestock emissions for each scenario were estimated by multiplying the emission factors for the different species and their offspring by the number of animals and the time period that these animals remained in the annual production system for the baseline scenarios and AMs separately and cumulated. The abated livestock emissions through application of AMs were estimated in a similar method as for the CO_2eq abatement in soil.

4.2. Cost-effectiveness (CE)

CE estimation combines the emissions scenarios with the discounted herders' net return during the baseline scenarios and during counterfactual AM scenarios. These net returns have been estimated as output of the region specific linear programming (StageONE) model. Estimation of the stand-alone CE (RMB/CO_2) for each AM is estimated as follows (equation 1).

$$Cost\ effectiveness_{AM} = \frac{Net\ return_{\ Baseline} - Net\ return_{\ AM}}{Abatement\ potential_{AM}} \qquad (1)$$

4.2.1. The StageONE model

The StageONE model (Takahashi *et al.*, 2011) is a linear program developed in Microsoft Excel to estimate seasonal feed balance in simple grazing systems in northern and western China. It consists of over 30 variables distinguishable into the following categories: i) pasture, ii) livestock, iii) costs and revenues, and iv) weather. The model is calibrated against the prevalent circumstances of the herders and grassland production system in the year 2010. It results in an annual financial report on herders' net-income, including costs for feeding, labour, machinery, animal husbandry, and benefits from selling produced goods. It can be indirectly used for management optimisation objectives by assessing the impact of management alterations on the livestock feed balance; hence changes in input costs and output benefits. The herders' financial performance is then assessed by comparing the financial reports of different management practices.

4.2.2. Grassland productivity, utilization and body weight

Annual revenue estimation for each scenario until 2036 requires assumptions for changing grassland productivity, animal body weight, and grass utilization, in turn dependent on grazing intensity. Accounting for the existing degradation of 20% less, 60% moderately, and 20% heavily degraded, total grassland productivity within the growing period from May to October was taken as 1025 Kg dry matter/ha /day, 628 Kg dry matter/ha /day, and 248 Kg dry matter/ha/ day, respectively. This was further subdivided into Kg dry matter/ha /day for the growing time (unpublished research results, IMAU). From this scenario, grassland condition and productivity was predicted to change gradually under different grazing intensities, until equilibrium was reached within 25 years (Randall *et al*., 2008). Body weight and grass utilization changed in relation to grazing intensity, which was 42 Kg, 40 Kg, 39 Kg, and 30%, 40%, and 60%, for LGI, MGI, and HGI, respectively.

4.2.3. Discounted net return

The Net Present Value (NPV) of the lifetime costs for implementing AMs was derived by subtracting the discounted net return (to be referred as "net return" throughout the paper) during the baseline scenario by the net-return during their counterfactual mitigation scenarios:

$$\mathrm{NPV(costs)} = \sum_{n=1}^{t}[\mathrm{Rb} * (1 - \mathrm{d}^{n})] - \sum_{n=1}^{t}[\mathrm{Rm} * (1 - \mathrm{d})^{n})] \tag{2}$$

where, t is the lifetime of the model approach; Rb is the net return at the baseline scenario; Rm is the net return at the mitigation scenario; and d is the discount rate.

The lifetime was set to 25 years and the discount rate to 5%. Capital costs for the suggested production system alterations were not considered as initial fixed-costs did not differ between different scenarios.

5. Results

5.1. Abatement potential

The cumulated abatement potential for the grazing system in Siziwang Banner corresponding to the baseline scenarios A1 and A2 was 62,523 Kilotonnes (Kt) CO_2eq and 32,018 Kt CO_2eq, respectively (Table 2 and Figure 3). Reduced stocking rate showed the highest abatement potential counterfactual to both baseline scenarios, whereas the abatement by shorter lambing time was low, with no impact on the CO_2eq content in soil (Table 2 and Figure 3). CO_2eq abatement in soil was much higher, compared to reduction in livestock GHG emissions.

Table 2: GHG emissions and abatement potential of each abatement scenario (Kt CO_2eq).

Scenario	Abatement /measure	Cumulative abatement	Abatement /measure /year	Livestock CO_2eq emission	Soil CO_2eq storage
A1-baseline				4,663	219,534
A1-shorter lambing time	40	40	1.60	4,623	219,534
A1-prohibited grazing	14,556	14,596	582.24	3,261	232,688
A1-reduced stocking rate	47,927	62,523	1917.08	2,806	265,603
A2-baseline				5,157	242,089
A2-shorter lambing time	128	128	5.12	5,028	242,089
A2-prohibited grazing	5,961	6,089	238.44	4,000	246,894
A2-reduced stocking rate	25,929	32,018	1037.16	2,528	265,390

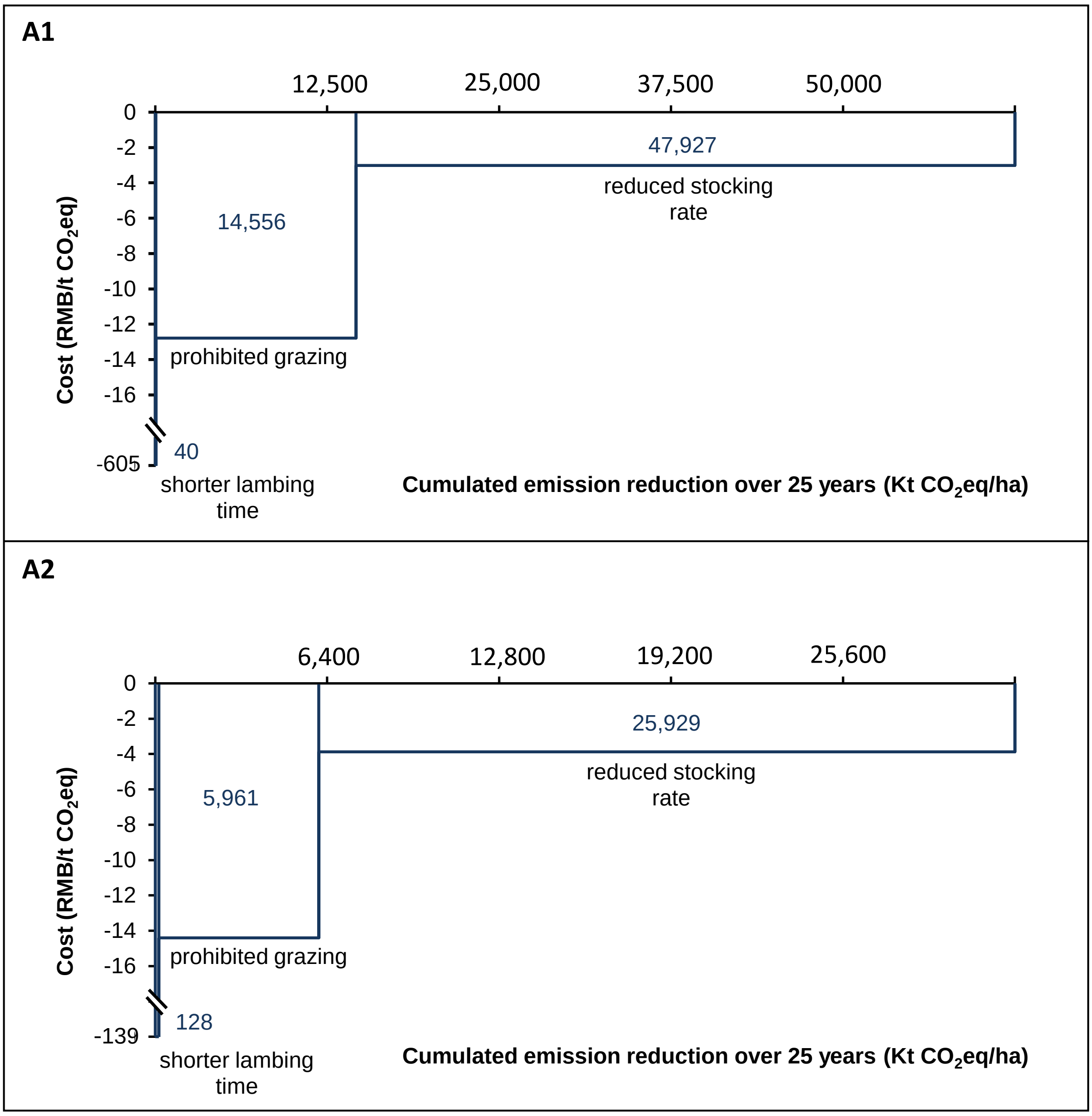


Figure 3: MACCs corresponding to the baseline scenarios A1 and A2. The x-axis shows the cumulated emission reduction due to abatement techniques over the lifetime of 25 years and the y-axis illustrates the costs of abating one t CO_2eq.

5.2. Cost and cost-effectiveness

Each AM showed negative costs per abated t CO_2eq in both baseline scenarios. In other words, the AMs actually lead to cost savings for the herders (Figure 3 and Table 3). Although both baseline scenarios showed a similar tendency of increasing net return per AM, the extent varied strongly (Table 3). Net returns increased for A1-prohibited grazing, A1-reduced stocking rate, A2-prohibited grazing, and A2-reduced stocking rate but just slightly for shorter lambing time relative to both baseline scenarios. Shorter lambing time was highly cost-effective while offering a small level of abatement. In contrast reduced stocking rate showed the lowest CE but the highest abatement potential (Tables 2 and 3).

Table 3: Discounted net return (RMB/ha) and the cost-effectiveness (RMB/CO_2eq) corresponding to each abatement scenario.

Scenario	Net return	Cost-effect.
A1-baseline	-237	
A1-shorter lambing time	-225	-605
A1-prohibited grazing	-145	-13
A1-reduced stocking rate	-165	-3
A2-baseline	-193	
A2-shorter lambing time	-184	-139
A2-prohibited grazing	-150	-14
A2-reduced stocking rate	-143	-4

4.2.4. Sensitivity analysis

The sensitivity analysis focused entirely on increasing input and output prices as they directly affect herders' net return. Consequently, the adoption potential of the AMs will be lower or higher depending on decreasing or increasing net returns relative to the baseline scenarios. The price variables for meat, fibre, and supplements were increased by 10%, first seperately and then all together. 10% higher meat prices strongly increased the herders' net return, thereby showing a positive net return for every scenario, except for reduced stocking rate. Higher supplement price had a strong negative impact on the economic performance (Table 4). These alterations consequently affect CE of the abatement efforts. Increased meat prices lead to lower CE for prohibited grazing and reduced stocking rate, to the extent that A1-reduced stocking rate, A2-prohibited grazing, A2-reduced stocking rate showed a positive CE. In contrast shorter lambing time had a higher CE (Tables 3 and 4). Higher supplement prices showed higher CE for shorter lambing time and lower CE for the remaining AMs.

Table 4: Net return (RMB/ha) and cost-effectiveness of abatement (RMB/CO_2eq) for different scenarios depending on variability in prices of meat, fibre, supplements and all together.

Scenario	**Meat price + 10%**	**Fibre price + 10%**	**Supplements price +10%**	**Price for all three factors + 10%**

	Net return	Cost-effect.	Net return	Cost-effect.	Net return	Cost-effect.	Net return	Cost-effect.
A1-basline	18		-196		-558		-258	
A1-shorter lambing time	48	-1489	-185	-575	-563	242	-245	-664
A1-prohibited grazing	34	-2	-116	-11	-369	-26	-158	-14
A1-reduced stocking rate	-11	1	-141	-2	-359	-8	-224	-1
A2-basline	87		-148		-535		-210	
A2-shorter lambing time	111	-380	-141	-117	-539	66	-201	-152
A2-prohibited grazing	66	7	-116	-11	-416	-40	-164	-16
A2-reduced stocking rate	-4	7	-121	-2	-318	-17	-157	-4

6. Discussion and Conclusion

While globally high abatement potential in grasslands is recognised, there are few studies demonstrating the economic abatement potential within the constraints of maintaining livelihoods. This study attemped to estimate the abatement potential of implementing climate smart agriculture in Inner Mongolia grasslands.

The grassland system in Siziwang Banner showed high economic abatement potential primarily through prohibited grazing and reduced stocking rates relative to both baseline scenarios (Figure 3). Reduced stocking rate is a promising abatement measure, allowing highest GHG abatement potential, highest net net return for herders, and the greatest improvement in grassland conditions. Although livestock' emission reduction show a low share of total abatement potential, mitigation efforts should focus on livestock potential since with improving carrying capacity of grasslands and increasing meat demand (discussed below), herders may tend to increase livestock numbers. Moreover, GHG emission reductions from livestock are permanent, compared to carbon storage in soil. This has important implications for the longevity of the estimated abatement (Barbier, 2011).

The most significant finding was that every AM led to financial savings for herders, reasoned by lower intensification and hence lower cost for supplementary feeding as compared to the baseline scenarios (Table 3). Implementation of all three abatement techniques would lead to savings of 355.5 million RMB which is equivalent to 76,100 RMB per herder within 25 years. This indicates a strong improvement in the herders' livelihood by applying climate smart agricultural systems. When dealing with the term 'climate smart agriculture', we need to approve tradeoffs in the objectives as food security might not be ensured initially by reduced production levels. But these measures lead to long term food security and improving herders' livelihood as the productivity of the grassland system will increase.

AM adoption is hindered by cultural and traditional practices developed over centuries. For instance, previous attempts by the Inner Mongolia Agricultural University to enhance the knowledge-base of the herders have had limited impact. Kemp *et al.* (2011) suggested that herders are in a transition stage from being keepers, mainly interested in maintaining a maximum livestock number, to producers, mainly focussing on productivity. This keeper philosophy may prevent reducing production levels. It is also questionable whether herders' knowledge on livestock management is sufficient to develop and implement sustainable management practices in current grassland conditions (Kemp *et al*., 2011). Further challenges are given by specific economic and demographic changes in China and the herders' dependency on selling meat as their main income source. Specifically, rising meat demand (and increasing prices) from an increasingly urbanising population is a growing pressure for intensification of production (Pingali, 2007). At the same time, government mitigation objectives to improve grassland conditions are a potential supply constraint leading also to a higher demand. This might undermine the adoption potential of the mitigation efforts based on reduced production level.

The sensitivity analysis focussed entirely on increasing input and output prices. Other variables during the MACC exercise also showed uncertainties, but input and output prices and especially meat prices are the key variables for the adoption potential of the AMs in a rapidly developing China. Increasing meat prices lead to costs for the AMs, A1-reduced stocking rate, A2-prohibited grazing, and A2-reduced stocking rate. Costs for applying AMs in turn decrease the adoption potential since the herders' economic situation do not allow additional investment costs. Unless there is no financial source for replacing these additional costs, it is unlikely to convince the herders about these management changes. Policies allowing equalization payments for applying these AMs could overcome this challenge. Such policies might also be necessary if the government intends to develop sustainable livelihoods for the herders in the near future.

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