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Economic Potential of Greenhouse Gas Mitigation Measures in Chinese Agriculture[1]

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Abstract

Emissions mitigation in China faces a range of challenges in terms of understanding sources of greenhouse gases (GHG) and the technical potential for reductions in each sector of the economy. Agricultural and land use emissions accounting is particularly challenging due to the biophysical complexity and heterogeneity of farming systems. SAIN research has contributed to improving our understanding of the *technical potential* of mitigation measures in this sector (i.e. what works). But for policy purposes it is important to convert this into a feasible *economic potential*, which provides a perspective on whether agricultural emissions reduction (measures) are low cost relative to mitigation measures and overall potential offered in other sectors of the economy. This note outlines the estimated economic mitigation potential available in China's agricultural sector. We develop a marginal abatement cost curve (MACC) representing the cost of mitigation measures applied to baseline agricultural practices. The MACC demonstrates that while the sector offers a maximum technical potential of 412 $MtCO_2e$ in 2020, a reduction of 131 $MtCO_2e$ is potentially available at zero or negative cost (i.e. a cost saving); and 346 MtCO2e (approximately 29% of the total) can be abated at a threshold carbon price ⩽ ¥ 370 (approximately £40) per tCO_2e. We outline the assumptions underlying MACC construction and indicate the barriers to realising the indicated level of mitigation.

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Introduction

GHG emissions from Chinese agriculture were 15% and 11% of national emissions in 1994 and 2005, respectively. This sector accounted for over 70% of national N_2O emissions and approximately 50% of national CH_4 emissions, mainly arising from the use of synthetic Nitrogen (N) fertilizers, livestock enteric fermentation, rice cultivation and animal waste management.

Existing global reviews (e.g. IPCC, 2007) suggest that agriculture offers significant technical potential to mitigate climate change through both emissions reduction and carbon sequestration in soils. In China, national policy aspirations for mitigation have until recently been eclipsed by food security objectives. Any convergence of production and climate objectives has focused mainly on increasing efficiency. In line with the 17% carbon intensity (carbon emissions per unit of Gross Domestic Product) cut and 10% ammonia emissions reduction targets outlined in the National 12th Five-Year Plan (FYP), the Ministry of Agriculture (MOA) initiated specific programs to improve agricultural productivity between 2010 and 2015. These include increasing fertilizer use efficiency by 3%, enhancing irrigation water use efficiency by 6%, and improving degraded grasslands.

In the scientific field, a range of technically feasible GHG mitigation measures has been identified as applicable in both arable and livestock systems. These can be broadly grouped into increased N-use efficiency, reducing rumen CH_4 emissions, sequestering C into cultivated and grassland soils, and energy efficiency to reduce CO_2 emissions. Some reviews (e.g. Wreford *et al.*, 2010), indicate that many mitigation measures can be implemented immediately using current technologies, simultaneously reducing input costs or improving outputs. Beyond such initial win-wins, some agricultural abatement options also afford co-benefits with regards to water quality, biodiversity conservation, food security, rural development and poverty alleviation, all of which have high importance in rural China.

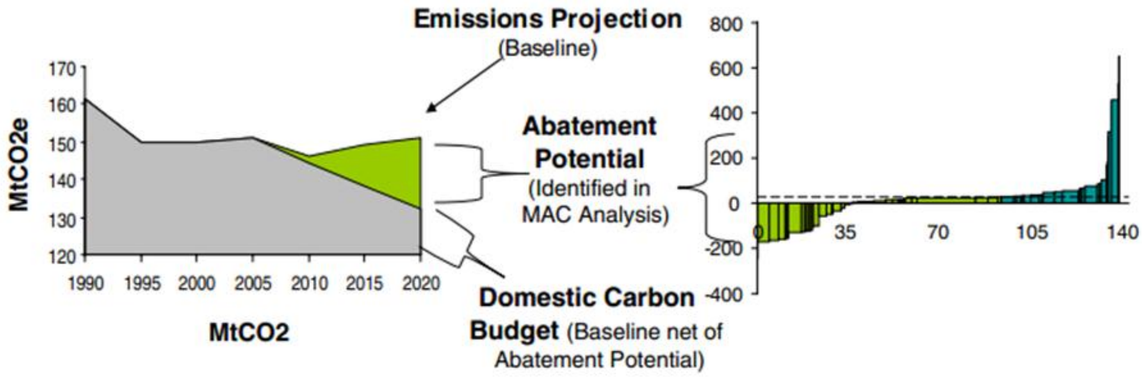
Existing research in China has quantified the technical abatement potential for specific agriculture mitigation measures (Lin *et al.*, 2005; Lu *et al.*, 2009; Huang *and Tang*, 2010; Saetnan *et al.,* 2013; Nayak *et al.*, 2013). Further insights have been provided by life-cycle analysis targeting the N fertilizer production and consumption chain (Zhang *et al.*, 2013). But there has been no cost-effectiveness analysis of abatement measures. This is significant, since the inception of emissions trading regimes in China is likely lead to an increasing focus on the relative cost of emissions reductions in all sectors of the economy.

Technical versus economic potential

In seeking to understand mitigation potential it is important to adopt a rational approach to evaluate competing mitigation measures that are technically feasible in agriculture. Most SAIN mitigation research has focused on the technical conditions for applying measures to work in the field under different biophysical conditions. In a first instance it is informative to know the maximum or upper technical mitigation potential that could be achieved if all technically feasible measures were fully implemented over and above a baseline or business as usual (BAU) level of activity.

But technically applicable measures will normally be differentiated in terms of their cost to farmers and wider society. Some measures will be relatively costly, and effective policy implementation should seek to implement the lowest cost measures first. An economic mitigation potential considers the cost of applying the measures as well as their adoption rate, which may be limited by institutional and farm-scale barriers. Hence, it is useful to rank abatement measures in order of decreasing cost-effectiveness (CE), and to estimate the annual cumulative potential (Figure 1, right hand side) of negative and low cost measures. An economic potential can be derived from selecting those measures that fall below a cost threshold set by a notional benchmark carbon price. Setting this threshold can rule out higher cost measures and thereby define an economic potential that is less than the full technical potential.

Figure 1: An illustrative "bottom-up" MACC and its relationship to a sector carbon budget



On the right hand side of the diagram each bar represents an abatement measure, differentiated by the implementation cost per tonne of CO2e? emissions reduced (height of bar), and the quantity of emissions the measure can mitigate if it is widely applied (width of bar). Measures below the x axis are cost negative – i.e. removing emissions and saving money. Those above incur positive costs. Therefore, the biggest financial gains and emission reductions can be seen in the longest and widest bars beneath the x-axis, and conversely, the bars above the x-axis are the costlier measures. Policy therefore needs to focus first on the implementation of the former. On the right hand side, implementing the most cost-effective measures above a BAU level of mitigation allows us to identify the added economically efficient mitigation potential Source: Moran et al.(2011)

MACC construction

We adopted a bottom-up approach to construct a country-wide MACC for a range of agricultural mitigation measures under the maximum feasible adoption scenario for 2020 (Beach *et al.*, 2008; De Cara and Jayet, 2011; Moran *et al.*, 2011). Despite spatial and temporal heterogeneity in agriculture, a bottom-up MACC provides an initial illustration of the magnitude of the CE and mitigation potential available in the sector.

Mitigation measures: cost-effectiveness and applicability

The bottom-up MACC approach considers all technically effective measures (Table 1); in this case, those applicable to Chinese agricultural conditions were identified by a process of literature search and expert opinion. Further explanation of measures for crop- and livestock sectors is presented in Annex Table S1 and Table S2, respectively.

Table 1: Mitigation measures applicable to China's agricultural sector

Crops and soils		Livestock and grassland	
No.	Measure	No.	Measure
C1	Fertilizer best management practices - Right rate	L1	Anaerobic digestion of manure
C2	Fertilizer best management practices (Wheat &Maize) - Right time and right placement	L2	Purebred breeding of livestock
C3	Fertilizer and water best management in rice paddies	L3	Ionophores addition to the diet
C4	Fertilizer best management practices (cash crops) - Right product, right time and right placement	L4	Tea saponins addition to the diet
C5	Enhanced-efficiency fertilizers	L5	Probiotics addition to the diet
C6	More efficient recycling of organic manure	L6	Lipid addition to the diet
C7	Conservation tillage for upland crops	L7	Grazing prohibition for 35% of grazed grasslands
C8	Straw returning in upland crops	L8	Reduction of stocking rate - medium grazing intensity
C9	Biochar amendment	L9	Reduction of stocking rate - light grazing intensity

Annual abatement rates (expressed as $tCO_2e\ ha^{-1}$ or $\%CO_2e$ animal $unit^{-1}$) of mitigation measures were derived from meta-analysis results primarily based on China-specific experimental data (Nayak *et al.*, 2013, Saetnan *et al.*, 2013). As a substantial component of the mitigation scheme, soil organic carbon (SOC) increments were also included in quantifying per hectare abatement rates.

The implementation costs of each measure (expressed as ¥ ha^{-1} or ¥ sheep $unit^{-1}$) were estimated by changes in yields, input (e.g. fertilizer, pesticide, seeds, feed additives, supplementary feeding), purchase costs, investment, labour, machinery and irrigation costs, compared to conventional practices based on Chinese statistical yearbooks. For livestock herders, data from different farm surveys in Inner Mongolia was used. Costs represent direct costs to farmers in complying with a measure. Indirect and social costs/benefits are excluded from the analysis. The former includes costs associated with changes in government subsidies and extension service improvement. Social costs refer to wider environmental impacts of implementing measures (e.g. reduced water pollution). The lifetime costs of each measure were converted to 2010 present values using a social discount rate of 7%.

MACC construction requires the definition of a BAU scenario to quantify additional emission savings from measure implementation. Following IPCC 2006 guidelines, BAU emissions were projected by combining forecast agricultural activity levels (CAPSiM modeled results) with China-specific emission factors related to N_2O emissions from cropland and manure management, and CH_4 emissions from enteric fermentation and manure management (Zhou *et al.* 2007; Gao *et al.*, 2011).

An estimate of *additional* maximum uptake to 2020 was based primarily on expert judgment and spatial (or per unit) applicability of the specific mitigation measure. This level of uptake was compared to a BAU scenario derived either from relevant policy targets or historical trends.

Measure interaction

The abatement rate and CE of one measure might be subject to change when applied in combination with others. In the case of arable crops, interactions are addressed by assigning implementation priorities to selected mitigation options. The abatement rates of the subsequent measures were therefore controlled to account for accumulated effects on N fertilizer reduction rates of prior measures. Further interaction allowances were made to avoid other measure overlaps (e.g. organic manure and biochar), or subordinating relationships (e.g. conservation tillage and straw returning). However, the efficacy of increasing organic manure will be discounted when applied jointly with conservation tillage or straw addition. We therefore assign an interaction factor (0.8) to the stand-alone abatement rates of the three measures on wheat and maize fields.

All three grassland mitigation options are mutually exclusive. Pasture grazing has to be specified as one intensity class. Lacking more detailed data, we assume that grazing controls or intensities are implemented in approximately 1/3 of the total grazed grassland in China. There is no interaction between the other livestock mitigation options, and applications of multiple feed additives have no additive effect on emissions or productivity. Hence, it is assumed that the farmer will not apply multiple dietary mitigation options. To avoid double counting, an equal application of each of the four dietary mitigation options is assumed; i.e. all livestock receive only one feed additive.

There may be residual interactions between measures within subsectors i.e. the crop and livestock sectors, however these interactions are beyond the analytical scope of this report.

Results

BAU emissions are shown by the red line in Figure 2. Abatement rate, CE, additional application, and overall potential of mitigation measures are summarized in Table 2 (refer to Annex for detailed information), and the MACC for Chinese agriculture is presented in Figure 3.

Table 2: Abatement rate, cost and mitigation potential of mitigation

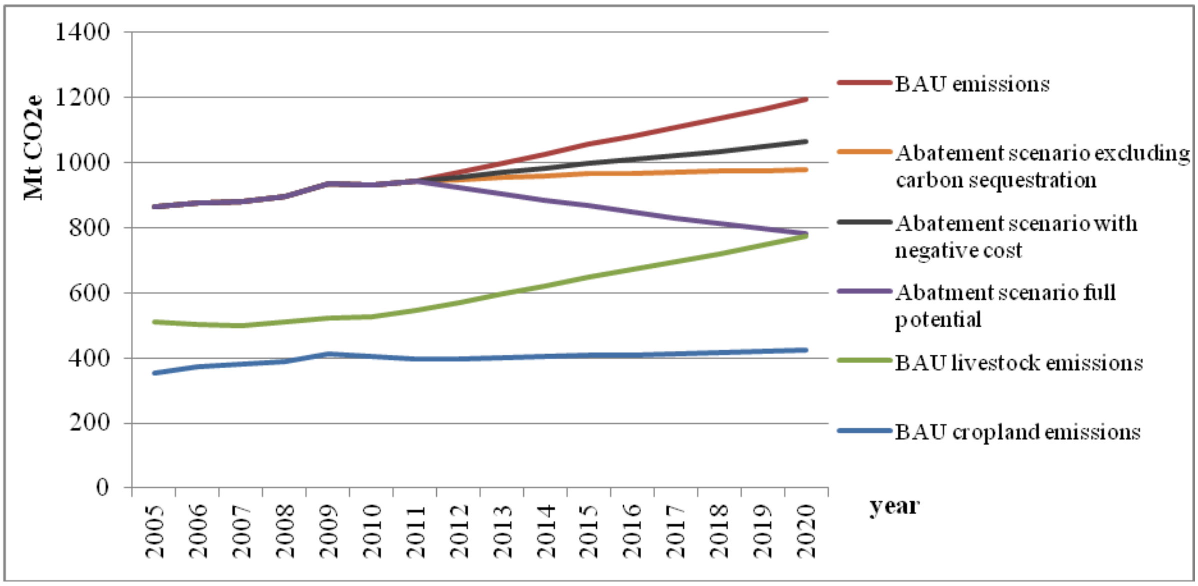
	Abatement rate (per year)		Cost (in 2020)		Cost effectiveness (in 2020)	Additional application (in 2020)	Mitigation potential (in 2020)
Measure No.	(tCO_2e ha^{-1})	(CO_2e reduction in % SU^{-1})	(¥ ha^{-1}, 2010 price)	(¥ SU^{-1}, 2010 price)**	(¥ tCO_2e^{-1}, 2010 price)	(M ha)	(MCO_2e)
C1	0.412		-228		-435	58.63	30.65
C2	0.201		-620		-3085	56.65	11.38
C3	1.337		464		347	17.93	23.98
C4	1.219		-2295		-1883	17.94	21.86
C5	0.271		63		231	57.23	15.54
C6	0.596		527		1576	120.11	40.19
C7	0.489		-107		-1692	22.98	1.46
C8	0.21		70		2209	30.06	0.95
C9	0.329		1804		5478	9.9	3.26
L1	2*		-500*		-32	***	58.66
L2		4.1		-28	-2005	***	4.27
L3		5.8		-43	-1668	***	1.95
L4		15.4		6	98	***	23.18
L5		0.6		-12	-5131	***	0.76
L6		14.3		126	2251	***	21.49
L7	1.067		300		281	56.98	60.78
L8	0.705		63		89	57.85	40.77
L9	0.877		317		362	57.85	50.72

* per anaerobic digester

** Sheep unit (SU) is a standard unit to compare different animal species. The conversion is sheep: 1, goat: 0.9, cattle: 5, dairy cow: 7. It is only an approximate simplification and normally applied in grazing systems. Hence the costs SU^{-1} should be interpreted with caution.

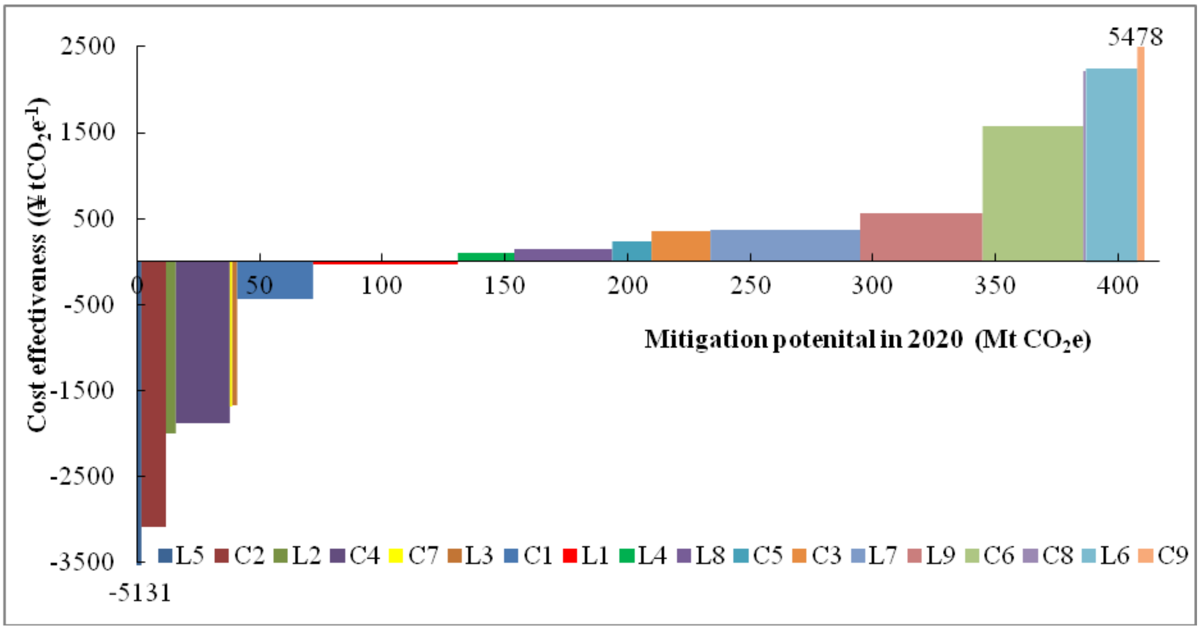
*** see Annex Table S5 for application potential

Figure 2: BAU and abetment scenarios for GHG emissions in the Chinese agricultural sector



Under the maximum feasible abatement scenario, annual emission savings are 412 MtCO_2e in 2020 (149 Mt from croplands), accounting for 35% of agricultural BAU emissions (Figure 3). Without accounting for carbon sequestration in soils, the emission savings are only 215 MtCO_2e in 2020, which is approximately 18% of BAU emissions (Figure 2). Figure 2 shows that in 2020 approximately 11% (131 Mt CO_2e) of the abatement potential can be realized with measures at negative costs and 346 MtCO_2e (approximately 29% of the total) can be abated at a carbon price ≤ ¥ 370 per tCO_2e.

Figure 3: MACC of maximum feasible abatement potential in 2020



The most cost-effective measures with highest mitigation potential are fertilizer best management practices that increase yields. In the case of livestock, supplementary feeding with probiotics and biomass gasification are promising negative cost measures, with the latter generating the second highest GHG reduction of all measures whilst also contributing to cost-savings through on-farm energy production. Although more efficient recycling of organic manure also offers significant abatement potential, substantial costs incurred by manure fertilizer purchase or labour requirements for composting may prevent its widespread application. Biochar application to soils and feeding lipids to livestock are high cost and may need considerable R&D to become economically feasible. The limited mitigation potentials of conservation tillage, straw addition, breeding practices and antibiotics feeding are due to high measures uptake under the BAU scenario, enforced by policy commitment or stringent political regulation. The abatement scenario in figure 3 assumes measure adoption at a linear rate over time.

Discussion

This analysis illustrates a maximum feasible mitigation potential that could reduce total agricultural GHG emissions by 412 MtCO_2e in 2020. In other words a 35% decrease from

BAU emissions. The most cost-beneficial measures are a) fertiliser best management techniques, b) conservation tillage, c) anaerobic digestion of manure, d) breeding of livestock, e) additive feeding of probiotics and f) additive feeding of antibiotics. Although antibiotics are a win-win option, application is likely to face resistance from consumers (Eckard *et al.*, 2010, Hvistendahl, 2012). Probiotics and tea saponins could offer a CE alternative application for rumen CH_4 reduction. Tea saponins are largely available in waste by products of tea production and access, and thus the cost-effectiveness of this feed additive could be improved with further research. The MACC results also highlight the importance of improved N fertilizer and manure management practices, coupled with improved irrigation systems.

A number of caveats can be placed on the analysis in this note, but all of these constitute part of a relevant research agenda in China. First, MACC construction involves some uncertainties in data leading to various assumptions for future prices, yield impacts, measure-applicability under both BAU and abatement scenarios, as well as variation in sequestration activities.

Second, this study only considered private costs incurred by farmers and the exercise could be improved by including ancillary costs that relate to other wider environmental costs and benefits. Including such data may change the cost-effectiveness of listed measures.

Third, although implementation of many measures would improve farm incomes there are several barriers leading to persistent overuse of fertiliser inputs. These include traditional responses to cheap (subsidised) inputs, a lack of formal training in fertiliser practices, and/or the availability of farm advice through extension services. The non availability of farm labour can also be a hindrance to efficient input use. These barriers and other anomalous behaviours and policy responses have been explored in Zhang *et al.* (2013) and Moran *et al.* (2013).

Despite these caveats, we suggest that the results provide useful information to inform current agricultural (including subsidy) policies, as well as improving agricultural infrastructure and extension services to overcome various barriers to measure adoption. To a broader extent, the estimated economic potential paves the way for identifying an agricultural contribution to national targets, either through offsetting projects or eventually as part of other trading arrangements.

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Annex:

Table S1 Explanation of crops⁄ soils mitigation measures and target crops

No.	Explanation	Target crops
C1	Reduce gross overuse of N fertilizers amount. We set regional optimal PFP_N * (Partial Factor Productivity of N fertilizer) derived from scientific fertilization recommendations[i] as the indicator for fertilizer efficiency improvement targets. This measure calls for a direct reduction in N fertilizer use for certain crops in targeted provinces to raise regional PFP_N to 70% of the optimal levels (Table S7).	Rice, wheat, maize, vegetable, fruit
C2	This strategy suggests postponing N fertilizer to a later stage of wheat and maize growth with preferably two top-dressings compared to the current one top-dressing practice, and popularizing fertilizer deep placement by using appropriate machines for maize top-dressing, in a bid to reach optimal PFP_N by increasing yield and further decreasing N rate.	Wheat, maize
C3	Split the total amount of N fertilizers into at least three applications for basal fertilization, early tillage, panicle initiation and heading stages; and shift from mid-season drainage (F-D-F) to intermittent irrigation (F-D-F-M).	Rice
C4	Promote fertilization (e.g. drip irrigation) for vegetables and cotton to save both fertilizer and irrigation inputs. As to fruits, controlling N rate and adjusting fertilization periods are essential to achieve sustainable fruit production. In addition, replacing part of ammonium-based fertilizers with nitrate-based products can also contribute to minimizing N_2O emissions and enhancing productivity.	Cotton, vegetable, fruit
C5	Use fertilizers added with nitrification inhibitors (NI) and/or urease inhibitors (UI) and slow- and controlled- fertilizers to reduce N_2O emissions.	All crops, vegetable, fruit
C6	The general objective is to increase animal manure amendment to soils to supply 30% of crop N nutrients demand and 50% of vegetables and fruit. Efficient recycling of animal manure should be in form of composed manure or bio digester residues to replace part of synthetic N fertilizers.	All crops, openfield vegetable, fruit
C7	Conservation tillage (CT) is a series of agricultural practices aiming to reduce tillage and soil disturbance to a minimum extent with at least 30% of residues incorporated into soil to increase soil carbon content in upland cropping systems.	Wheat, maize
C8	Returning straw or residue back to field is considered a stand-alone farming practice in China which only involves changes in straw management compared with CT measure. This technique is an important way to improve soil organic matter content and soil physical properties if properly tailored to different cropping systems and local farming practices.	Wheat, maize
C9	Application of biochar produced with crop straw pyrolysis can significantly decrease N_2O emissions and improve soil prosperities to enhance yields.	Rice, wheat, maize

* PFP_N -Partial Factor Productivity of N fertilizer is an indicator of N nutrient use efficiency, measured by the grain yield per N nutrient input (kg kgN^{-1})

Table S2 Explanation of livestock mitigation measures and target species

No.	Explanation	Target species
L1	Implementation of on farm anaerobic digesters for storing livestock manure residues and converting some of the organic content to CH_4. CH_4 can be burned to produce heat or electricity for the livestock farm or sold to other consumers.	cattle, dairy cows, sheep, goat, pigs, horse, asses, mules, poultry
L2	Breeding techniques like artificial insemination of domestic livestock with high quality semen from breeding stock will generate a trade-off between decreasing rumen CH_4 production and improved feed intake, milk production, weight gain and production efficiency. This measure does not consider cross breeding.	indoor - cattle, dairy cows, sheep, goat
L3	Ionophores are antibiotics which are commonly used as growth and efficiency promotion in livestock production. The improved productivity leads hence to a reduced outcome of GHG per unit of product. However, the application is in China strongly regulated.	indoor - cattle, dairy cows, sheep and goat
L4	Tea saponins are plant secondary compounds that are available in highly concentrated form in waste by products of tea production. Adding tea saponins to the diet of livestock is considered to increase the productivity while reducing rumen CH_4 production.	indoor - cattle, dairy cows, sheep and goat
L5	Probiotics are commonly used in Chinese aquaculture industry but the application is uncommon for terrestrial livestock. Adding probiotics to the diet modifies the rumen ecosystem and thereby reduce the CH_4 production as well as improve the animal productivity and immune response.	indoor - cattle, dairy cows, sheep and goat
L6	Adding polyunsaturated fatty acids to the diet of livestock can effectively reduce the CH_4 production through suppression of rumen protozoa and inhibition of methanogens in the rumen and increase the productivity of the animal.	indoor - cattle, dairy cows, sheep and goat
L7	Grazing ban is a common technique in grazing systems for improving degraded grasslands. This measure considers a ban of 35% of the total grazed grassland in China. While the vegetation type is recovering, the dry matter production is improving. The grass will not be cut and thus grass residues can enter the soil to improve the soil organic matter content and increase the carbon sequestration rate.	grazing - cattle, dairy cows, sheep and goats
L8	Chinese grasslands are usually overgrazed. This measure considers a stocking rate reduction to a medium intensity. While the grassland condition is improving, the dry matter production of the grasslands would increase by 10%. The grassland utilization rate is reduced to 50% and thus the higher amount of organic material entering the soil will increase the carbon sequestration rate.	grazing - cattle, dairy cows, sheep and goats
L9	This measure considers a light grazing intensity on Chinese grasslands. As a result the grassland utilization rate is reduced to 35% and the dry matter production increases by 3%. Similar to L8, the carbon sequestration rate increases due to a higher organic matter input to the soil.	grazing - cattle, dairy cows, sheep and goats

Table S3 Mitigative effects, effects on yield and stand-alone abatement rate of crop mitigation measures

No	Mitigative effects			Effects on yield increase	Abatement rate ($tCO_2e\ ha^{-1}$)							
	N_2O	CH_4	SOC		Rice	Wheat	Maize	Other upland crops	Greenhouse vegetable	Openfield vegetable	Fruit	Averaged
C1	-				0.075	0.351	0.406		1.225	0.505	1.266	0.412
C2	-			5%-8%		0.190	0.208					0.201
C3	-	-		5%	1.337							1.337
C4	-			10%				0.903 (cotton)	1.376	0.829	1.827	1.219
C5	-				0.127	0.273	0.256	0.274	0.667	0.369	0.616	0.271
C6	+	+*	+		0.460	0.551	0.459	0.631		0.227	0.462	0.596
C7	+		+			0.489	0.489					0.489
C8	+		+			0.210	0.210					0.210
C9	-			5%-10%	0.187	0.364	0.342					0.329

Notes: + denotes reduced emissions or enhanced removal (positive mitigative effect);

- denotes increased emissions or suppressed removal (negative mitigative effect);

* Here CH_4 emissions increase is only applied to rice paddies

Table S4 Mitigative effects, effects on yield and stand alone abatement potential of livestock mitigation measures

No	Mitigative effects			Effects on yield increase	Abatement rate (per year)						
	N_2O	CH_4	SOC		Cattle (%/head)	Dairy cow (%/head)	Sheep (%/head)	Goat (%/head)	Average (%/head)	Grassland (tCO_2e ha^{-1})	Anaerobic digester (tCO_2e $digester^{-1}$
L1		+									2
L2		+		1%	-11	6	8	8	4		
L3		+		7%	7	6	13	13	6		
L4		+		5%	12	15	17	17	15		
L5		+		7%	-0.2	0.3	1	1	1		
L6		+		5%	8	6	4	4	4		
L7	+	+	+	1%						1.07	
L8	+	+	+	10%						0.7	
L9	+	+	+	3%						0.88	

Table S5 Application potential of livestock mitigation options

No.	Application potential
L1	The amount of additional anaerobic digesters are 80 million and 40 million in 2012 and 2020, respectively. A linear increase is assumed.
L2	20%, 30%, and 60% in beef/cow-, sheep-, and goat farms, respectively
L3	20% in beef farms
L4	60% in beef, dairy, sheep and goat farms
L5	50% in beef, dairy, sheep and goat farms
L6	60% in beef, dairy, sheep and goat farms