Study on GHG Emission Effects of Ecological Engineering Measures in a Land Consolidation Project: A Chinese Case

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Summary

In recent years, the ecological effect has already become one of the fundamental objectives for land consolidation (LC) projects in China which also conforms with the country's new development strategy of "promoting ecological progress". Meanwhile, as China determinates in reducing its Green House Gases (GHG) or carbon emissions to combat climate change, the GHG emissions due to land consolidation draws growing attentions. Presently, limited researches address the GHG emission effects during land consolidation processes; fewer addressed the issue from an ecological land consolidation perspective. This paper, hence, studies on the GHG emission effects of a pilot land consolidation project in China which featured by many ecological designs and engineering measures applied. According to findings from the case study, we argue that, in comparison to the conventional engineering measures applied in typical land consolidation projects of the region, most of the ecological engineering measures can not only enhanced the ecological effects in the project area, but also reduce GHG emissions due to savings in material use, transportation and energy consumption during the land consolidation process with additional advantages in cost efficiency.

Zusammenfassung

In den letzten Jahren sind die ökologischen Wirkungen der Flurbereinigung in China zu einem zentralen Anliegen geworden. Das geschah in Übereinstimmung mit der nationalen Entwicklungsstrategie »Förderung des ökologischen Fortschritts«. Da China sich inzwischen verpflichtet hat durch Reduktion von Treibhausgasen und Kohlendioxid den Klimawandel zu bekämpfen, erzeugen auch die Treibhausgasemissionen in der Flurbereinigung wachsende Aufmerksamkeit. Gegenwärtig befassen sich einige Forschungsansätze mit Treibhausgaseffekten in der Flurbereinigung, andere mit den ökologischen Aspekten. Die vorliegende Studie beschreibt die Treibhausgasemissionen in einem chinesischen Flurbereinigungsprojekt, das ökologische und ingenieurbauliche Maßnahmen aufweist. Die Studie zeigt, dass ökologische Baumaßnahmen im Vergleich zu herkömmlichen Maßnahmen nicht nur die ökologischen Wirkungen im Projektgebiet vergrößern, sondern auch infolge von Einsparungen an Material und Energie die Treibhausgasemissionen verringern sowie die Kosteneffizienz positiv beeinflussen können.

Keywords: ecological land consolidation, GHG reduction, engineering measures, case study, China

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1 Introduction

1.1 Background

Land consolidation (or LC hereafter) in China focuses on maximizing overall effects of land utilization by consolidating, readjusting, and developing underdeveloped, unreasonably arranged or unused land as well as reclaiming land that was contaminated and damaged by human activities and natural disasters (Wu et al. 2004). The Third Plenary of the 17th Chinese Communist Party Meeting clearly addressed to continue the work of LC with strengthened considerations on ecological protection under the country's new development objective of "Promoting Ecological Progress" (or literally translated as "Establishing Ecological Civilization"). As stated in the "National Plan of Land Consolidation and Rehabilitation 2011–2015", ecological protection should be integrated within LC as one of the fundamental principles; comprehensive effects, namely economic, social and ecological effects should be pursued. Advocating the *Ecological Land Consolidation* (or *Eco-friendly Land Consolidation*) is a concrete progress for China in exploring its route for more sustainable use of land. It indicates that the objective of LC in China has been shifted from solely pursuing the quantity and productivity of farmlands to the maximization of overall effects. Several existing procedural guidance documents regarding LC already specify that attentions should be paid to indicators of ecological impacts and effects ("Key Points on Provincial Land Development and Consolidation Planning" (2002), "Land Development and Consolidation Planning Procedures" (TD/T 1011-2000), "Land Development and Consolidation Project Planning and Design Requirements" (TD/T 1012-2000) and "Land Consolidation project Design Report Requirements" (TD/T 1038-2013)), such as forest cover rate, area of treated soil erosion, density of shelter-belt plantations, soil and water pollution. Ecological protection gradually becomes the main task and objective of land consolidation and rehabilitation projects in China nowadays.

As a comprehensive and systematic engineering process, LC projects unavoidably affect the carbon emission and storage capacity of the project area. However, the enacting policies and procedural guidance documents rarely consider the Green House Gases (GHG) emission or carbon emission effects due to LC projects, especially the engineering specifications on carbon emission are absent.

From an international perspective, the "Climate Change Synthesis Report 2014" (IPCC 2014) states that globally,

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24 % (net emission) of GHG emissions were released by agriculture, forestry and other land use (AFOLU) in 2010. According to a FAO (Food and Agriculture Organization) research, the total GHG emission by AFOLU sector in 2010 is the equivalence to 10 billion tons of CO_2, whereas the total carbon storage capability of AFOLU sector is merely 2 billion tons annually (FAO 2014). It is evident that a reducing of carbon emissions in AFOLU sector is a pressing global issue.

In recent years, the Chinese State government has been very active in responding to issues of climate changes, reduction of carbon emission and eco-environmental protections. In 2007, the State government issued the "National Program for Addressing Climate Change" as a national level action plan in accordance to the "United Nations Framework Convention on Climate Change". In 2009, the Chinese government made the promise to the international community to reduce its CO_2 emission per unit of GDP by 40 % to 45 % from the 2005 level. In 2015, China submitted the "Enhanced Actions on Climate Change" to the UNFCCC secretariat, in which China has mapped out how it will try and peak GHG emissions by 2030 or before as well as to lower CO_2 emissions per unit of GDP by 60 % to 65 % from the 2005 level. These efforts demonstrate the unwavering determination and commitment of China as the biggest emitter of GHG in the world. In April 2015, the Chinese Communist Party and the State Council issued *"Opinions of Hastening the Promotion of Ecological Progress"*, in which *"Green Development"*, *"Cyclic Economy"* and *"Low-carbon Development"* are proposed as basic approaches in achieving an *"Ecological Civilization"*. It also highlights that an optimizing land use, increases the efficiency of resource utilization and protects the eco-environment as key objectives. The progress on both international and domestic initiatives and policies indicate that LC should not only pay attention to the ecological benefits but also more to the carbon emission effects.

1.2 State of the art in eco-friendly land consolidation in China

There are many academic researches on subjects related to ecological or eco-friendly land consolidations in China. The focal points of theses researches cover a wide range of topics. Mainly, they cluster on topics like, the evaluation of ecological effects as well as the evaluation methods for LC projects (Hu and Yang 2004, Ding et al. 2011, Wang et al. 2012a, Wang et al. 2014), the regional ecological impacts due to LC projects (Ye et al. 2001, Luo and Zhang 2002, Niu et al. 2008, Li et al. 2010), or the evaluation ecological risk of LC projects (Yang 2003, Wang et al. 2012b), as well as impacts of LC in terms of regional landscape ecology (Yang et al. 2005, Zhang et al. 2007, Liu et al. 2008). There are also researches focusing on the stability evaluation of the regional ecosystem and the ecological compensation measures for LC projects (Yu et al. 2008, Qu et al. 2010).

Comparatively, the studies which discuss LC from a carbon emission perspective are not as popular. Some studies of related subjects mainly focus on analyzing the relationships between land use and the carbon storage capability of an area (Houghton 2002, Houghton and Hackler 2003, Qu et al. 2011, Zhang et al. 2013, Lai et al. 2016), the modes of low-carbon land use (Li and Lu 2010, Zhao et al. 2010, Zhao et al. 2014), or the evolution of carbon storage capabilities of farmland (Pan et al. 2009, Huang et al. 2010, Dang et al. 2014, Li and Shao 2014, Zhang et al. 2014a, Zhang et al. 2014b). Only a few studies discuss the carbon storage capacity in relation to LC projects. Among them, some found out that the overall carbon storage capability (including carbon stored by both soil and plantation) in the area was increased after the implementation of LC project, though such increase mainly attribute to the increased areas of farmland and improved productivity of crops; in other words, more land for farming and more plantation produced per unit of land enlarge the carbon storage by volume. Meanwhile, there are also studies showing that some LC projects have largely altered the land use structure of the area in the case that orchards and forests were converted for farming, which means plantations of high carbon storage capacity (i. e. trees) were replaced by the lower (i. e. crops). In such cases, the overall carbon storage was decreased after the LC projects (Guo and Dun 2015). Also, according to the findings based on the carbon storage data of soil in farmland that have been intermittently collected for almost forty years from an agricultural experimental zone in Quzhou county of Hebei Province, the overall carbon storage capacity increased from 1.34 million tons in 1973 to 2.32 million tons in 2013. However, only the storage capacity of crops has been continuously increased, whereas the storage capacity of soil has been increased in first three observations that took place in 1973, 1985 and 1999; and then declined in the period from 1999 to 2013 (Hao et al. 2016). The aforementioned studies showed that LC projects, with different planning objectives and engineering components, could have positive or negative impacts to the project areas in terms of carbon storage capacity. Considering carbon stored by crops or plantations, the increases in size or productivity of farmland due to LC also increase the crop yields, or in other words more plantations available for carbon storage in the area. Meanwhile, the alterations in the land use structure, for instance, the decrease in forests and orchards, could cause reductions of carbon storage capacity. Current studies could not confirm a unanimous result on the potential impacts on the carbon storage capacity by soil after LC. Potentially, numerous factors could contribute to the changes of carbon storage conditions in an area; in addition to variables of diversified engineering components that could be employed in LC projects, all could influence the findings or conclusions of a particular research.

Therefore, recent studies starts to concentrate on the GHG emission during the engineering process of LC projects, particularly focus on the GHG emissions during the uses and transportations of engineering materials as well as the energy consumed by machineries. Some studies show that the majority of GHG emitted in LC projects in China come from the engineering measures such as land levelling (i.e. removal of surface soils and precision replacement), construction of roads, irrigation and drainage systems (Chen 2012, Guo and Dun 2015). Moreover, the materials that being used and transported during the construction process such as cement and steels as well as diesel fuels and electricity consumed are the major sources of carbon emission (Zhang and Jin 2016).

As the "IPCC Guidance on National GHG Inventory" and the "Provincial GHG Inventory Compilation Guidelines" articulate the general approaches and standards for calculating the volume of carbon emission as well as emission factors related to engineering projects, the methods for evaluating the volume of carbon emission during the construction process of a LC project are already in place. Furthermore, as modern technologies applied in project management avail accurately tracing of various inputs during the whole construction process, it is possible to collect reliable data on materials, energy consumption, labor and mechanic power utilized, in other words, to estimate GHG emission levels of engineering measures with a aggreeable precision.

This study, therefore, will focus on evaluating the carbon emission effects of various ecological engineering measures applied in a LC project in comparsion with the average level of the conventional LC projects, i.e. LC projects without specific ecological measures.

2 Case Study: A Low-carbon and Ecological Land Consolidation Project in China

Currently, there is no readily available approach or method that could be internationally and unanimously accepted for evaluating the carbon emission effects for an ecological LC project. Therefore, the Ministry of Land and Resources of P.R. China (MLR) and Die Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH together launched a cooperative project themed as the "Sino-German Low-carbon Land Use Programme" to explore a new method for GHG emission evaluation. The project is funded by the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety, implemented by the Ministry of Commerce of the P.R. China, the Land Consolidation and Rehabilitation Centre (LCRC) of the MLR and GIZ. The programme selected Changsha county in Hunan Province as the area for the pilot project.

2.1 Basic Information on the Pilot Project

With supports from the "Sino-German Low-carbon Land Use Programme" , Hunnan province launched the "Ecological Land Consolidation Project in Jianshan Village, Jinjing Township, Changsha County". The project is the first LC project that integrated both ecological protection and low-carbon engineering measures in China.

Topographically, the project area lies in a hilly area with most of the arable land in the hilly zones but with slopes of less than 5°, flat land along the two banks of the Jinjing River, and the remainder located between the hill ridges. The project area is 277.34 hectares, and the project budget was CNY 14.18 million (i.e. about 2 million Euro). The project was planned and designed in accordance with the required standards of the "High Standard Basic Farmland". The main engineering components include: land levelling, irrigation and drainage system development, field access road construction and measures to protect fields and the ecological environment (see Tab. 1). Development of irrigation and drainage systems and the field access road construction are the major tasks of this project. Apparently, from the engineering component perspective, the pilot project is quiet similar to a conventional LC project; the differences concern the eco-friendly engineering design and other applied ecological measures.

In the column of "Engineering Components", comparing to the conventional LC projects, the pilot project added (IV) Retention of Wetland and Water Filtration Ponds and (V) Biodiversity Conservation Measures in its plan. In the column of "Quantity of Works", numbers inside parentheses mean the part that certain ecological engineering measures were employed. In the project, ecological measures were mainly implemented in (I) Irrigation, Drainage and Ponds, (II) River Bank Treatment and (III) Field

Tab. 1: Main Engineering Components of the Pilot Project

Engineering Components	Quantity of Works
I. Irrigation, Drainage and Ponds	▪ Irrigation Channel 6.45 km (1.70 km) ▪ Channels with both Irrigation and Drainage Functions 4.57 km ▪ Feeder Channels 29.71 km (29.71 km) ▪ Drainage Channels 4.88 km (4.38 km) ▪ Drainage Ditches 12.06 km ▪ Ponds 16 (15)
II. River Bank Treatment	▪ 1.57 km (1.57 km)
III. Field Access Roads	▪ Roads 4.92 km (4.92 km) ▪ Agricultural Roads 22.77 km
IV. Retention of Wetland and Water Filtration Ponds	▪ 2 (2 Biological Filtration Ponds)
V. Biodiversity Conservation Measures	▪ Migration Corridors 165 ▪ Bio-Habitat 152
VI. Land Levelling	▪ Digging Soil 54,600 m^3 ▪ Removing and Replacement of Surface Soil 94,700 m^3 ▪ Construction of Paddy Ridges 9,800 m^3 ▪ Manual Levelling 62.35 ha

Source: Land Consolidation Plan for the "Ecological Land Consolidation Project in Jianshan Village"

Access Roads. And the rest without specifications means the conventional measures that were applied. This study will further analyze the introduced ecological measures in detail as well as discuss their ecological effects and benefits to the project area.

2.2 Ecological Measures and Effects of the Pilot Project

The ecological considerations of the pilot project are mostly highlighted by various eco-friendly designs used on the hydraulic works (specifically, the developments of irrigation and drainage system as well as treatments on banks and bottoms of ponds and the river) and the developments of field access roads.

Usually, in the conventional LC projects, the concrete lining measure (i. e. applying concrete or using pre-fabricated panels to line channel banks and bottom) is applied, as to the development of roads, the hard surfaced designs, particularly the gritstone surface, are regularly used in the region. These designs may have the advantages of sturdiness and water stability as well as facilitate the drainage of surface flow. However, they are also disadvantageous in preventing water logging of fields and disturbing the migration routes of animals, breaking biological food chains, resulting in a decline in biodiversity, and even the disappearance of some species of plants and animals.

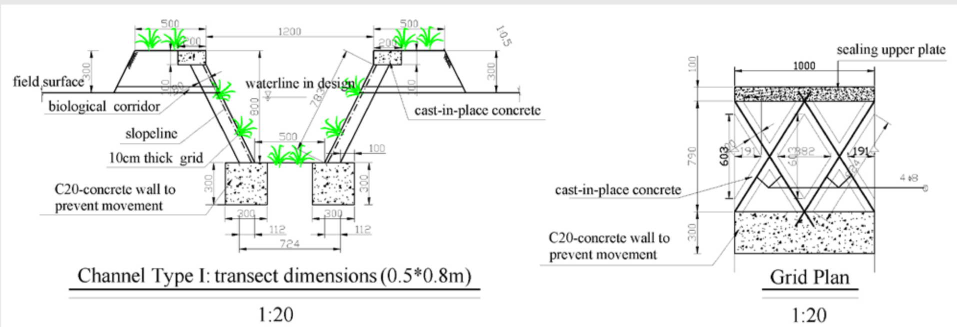
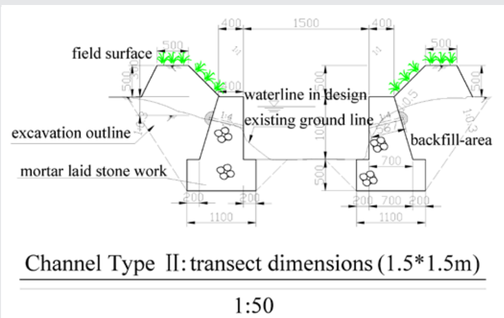
2.2.1 Ecological Measures and Effects in Hydraulic Works

Particularly, during the construction and embankment of banks of channels, ditches, ponds and the river, the pilot project abandoned the design of full lining with concrete or cements which is rather popularly used in the conventional LC projects; instead, the ecological measures applied with the interlocking bank lining bricks or cement frames that were only laid up to the designed water line above which sod revetment or grassed slope protection measure was used. Also, habitat spaces are intentionally left in the interlocking bank lining bricks. Meanwhile, the project also discarded the harden surface lining design for the bottom of channels, ditches, ponds or the river. Tab. 2 shows six types of designs for such ecological measures that applied in the project. And, Fig. 1 and 2 shows the drainage channels and river banks with the conventional

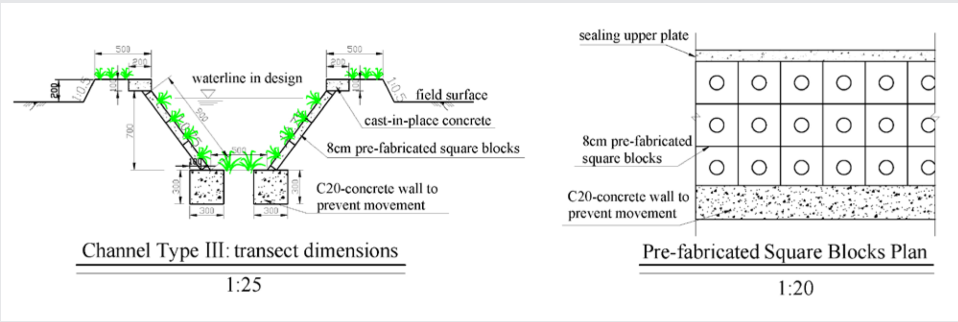
Fig. 1: Channels with conventional (left) and ecological lining measure (right)

Fig. 2: River embankments with conventional (left) and ecological lining measure (right)

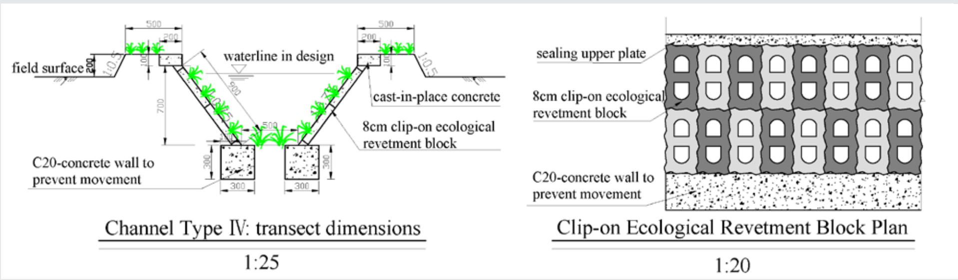
Tab. 2: Ecological Designs for Channel Lining

a) Channel Type I: transect dimensions 0.5 × 0.8 m, sloped, using grid made of concrete onsite to line banks, with ample space for hydrophilic plants to grow. The bottom has concrete to prevent movement of the gridded bank lining, but the bottom is not lined.	
b) Channel Type II: transect dimensions 1.5 × 1.5 m. Both sides use laid masonry up to height of 1.0 m, above which is 0.5 m unlined sloped bank (slope 1:1) for plants to grow. The bottom is not lined.	

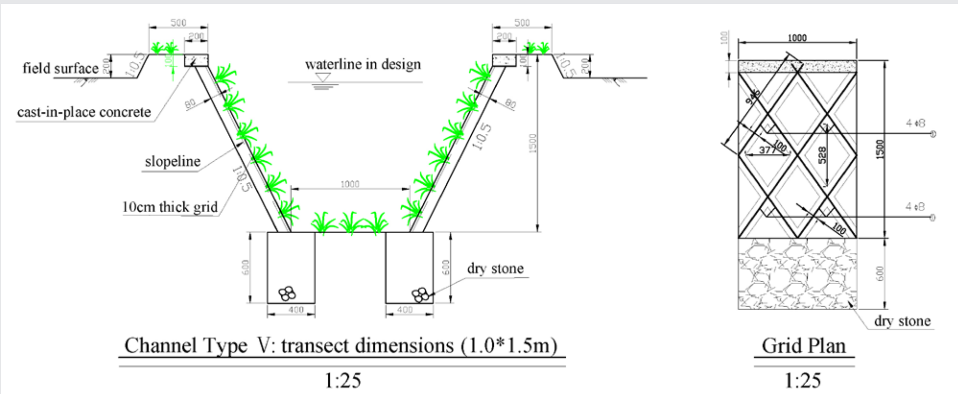
c) Channel Type III:
transect dimensions 0.5 × 0.8 m slope 1:0.75. Banks use 8 cm thick pre-fabricated square blocks (0.3 × 0.3 m) for wall lining, in the middle of each block is a φ100 hole for plant growth. The bank top is concrete and the bank base has concrete to prevent wall lining movement, but the base is not lined.



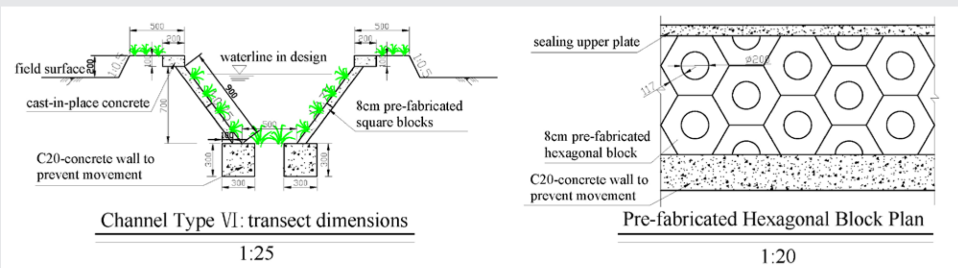
d) Channel Type IV:
sloped walls (1:0.75), b × h = 0.5 × 0.8 m. Bank lining uses interlocking blocks with holes for plant growth. The bank top is concrete and the bank base has concrete to prevent wall lining movement, but the base is not lined.



e) Channel Type V:
sloped walls, b × h = 1.0 × 1.5 m. Use grid made of concrete onsite to line banks, with ample space for hydrophilic plants to grow. The bottom has stone to prevent movement of the gridded bank lining, but the bottom is not lined.



f) Channel Type VI:
sloped (1:0.75), b × h = 0.5 × 0.8 m. Wall lining uses hexagonal blocks with a hole for plant growth. Wall top is concrete, and wall base is concrete to prevent wall movement.



Source: Hunan Xinyu Planning and Design Co Ltd. (2014)

lining measures (on the left), in comparison to the result of the interlocking bricks lining (on the right).

The ecological measures, i.e. the interlocking blocks, ensure a precise placing for each block to prevent sideways movement, so the river or channel banks are quickly fixed in place. At the same time, different types of plants (e.g. submerged plants, emergent plants and terrestrial plants) can grow in the holes in the bricks or frames and on the embankments above the water line. These plants serve to stabilize the embankments in the longer term, prevent soil erosion, and prevent eutrophication of water bodies. In the drainage process, nutrients can be captured and absorbed in mud on channel bottoms, by plants and by microbial degeneration. In this case, the drainage system performs the role of a nutrient sink. Nitrogen and phosphorous can also be absorbed by plants and removed from the ecosystem by harvesting, or temporarily fixed in the drainage channels through microbial activities. When there are more nutrients than the capacity of the system can process, the irrigation and drainage system will also transport the excessive nutrients out of the field into the wider environment where it functions as the source of nutrients.

2.2.2 Ecological Measures and Effects in Field Access Roads

In the project, a more eco-friendly road surface design – the clay-bound gravel surface – replaces the gritstone surface which is usually applied in the conventional

LC projects in the region. The gritstone road surface has the disadvantages of lack of viscidity and integrity, which could be easily loosed up or damaged after being grind by machineries. Nevertheless, the clay-bound gravel surface that was treated by grouting and roller compaction technics, advantages by exploiting the interlocking denseness effect of gravels as well as the viscidity of clay. The spaces among gravels are filled by clay mud, along with stone chips scattered on top; together they form into a condensed and solidified unity. The design can on the one hand, fulfill the demands for road access in agricultural operations, and on the other hand, provide habitats and corridors for animals or plants in different ecological

Fig. 3: Field access roads with gritstone (left) and clay-bound gravel (right) surfaces

patches, which is beneficial for the protection and conservation of eco-system. Fig. 3 compares the end results of both gritstone (on the left) and clay-bound gravel (on the right) surfaces.

2.2.3 Ecological Measures for Biological Corridors, Habitats and Filtration Ponds

Irrigation and drainage channels form the ecosystems that composed of water, soil and biological elements with unique structures, and can also be viewed as an agro-ecological wetland ecosystem. Biological communities are made up of plants, reptiles, fish, amphibians, birds and mammals. These ecosystems are semi-natural ecosystems on the margins of fields that are clearly affected by cultivation, fertilization, pesticide use and other activities in the neighboring fields. When ecological measures are used in the irrigation and drainage network, they may have higher biodiversity than in the fields. Channels and embankments provide habitats and refuges for fish, shrimp, benthic fauna, frogs, toads and birds. In the project site, biological corridors were deliberately put in place in locations between fields and channels, and between irrigation and drainage channels and river channels (see Fig. 4 left). The biodiversity habitats were also placed in connections with these corridors (see Fig. 4 right). This may increase the habitats and refuges for biological organisms, and increase biodiversity throughout the landscape.

Biological filtration ponds were also planned in the project (see Fig. 5). The ecological drainage channels can collect water from the fields where water is filtrated by the sub ecosystem in channels and then flows into

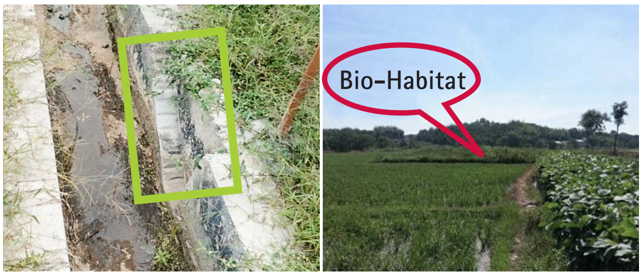


Fig. 4: Biological corridor (left) and Bio-Habitat (right)

Fig. 5: Biological water filtration pond

an biological filtration pond, where plants (e.g. Acorus calamus, Lythrum salicaria and reeds) can absorb free ammonium ions ($NH4+$) and phosphorous. This reduces the contents due to excess fertilizer and pesticide use in the water before discharge from the agro-ecosystem into the wider watershed. Hence, the irrigation and drainage system as well as the biological filtration ponds combine into a comprehensive system with both landscaping and biological functions.

3 Evaluation on the GHG Reduction Potentials of the Pilot Project

3.1 Evaluation Standards and Methods

In order to comparatively evaluate the GHG reduction potentials of the project, it is necessary to identify the average GHG emission levels of similar engineering components in the conventional LC projects. Firstly, as a precondition, both the ecological and conventional LC measures must be all in line with the stipulated designing and construction requirements by enacting planning and building standards, guidelines or documents for LC projects. Secondly, the GHG sources and the emission standards must be identified. The study employs the approaches articulated in the "Provincial GHG Inventory Compilation Guidelines" issued by the State Department of China. Thirdly, it was to establish a "baseline scenario" for the evaluation, i.e. to find out the average GHG emission levels of various engineering measures in the conventional LC projects of the region, i.e. Hunan Province. The study selects three finished and large-scale LC projects as the sample from the "Land Consolidation Plan of Hunan Province 2011–2020". The total construction areas of the sample projects cover about 676,100 hectares. The data of the construction processes of the sample projects, such as material used and energy consumed, were collected and calculated for determining the average inputs of a typical conventional LC projects in Hunan, i.e. the baseline level for further evaluation. Lastly, the study applies the *emission factors* listed in the "Provincial GHG Inventory Compilation Guidelines" as the multipliers for the evaluation. For the convenience of measuring, different types of GHG emissions were translated into the unit of t CO_2 (tons of carbon dioxide) equivalent.

The studied key GHG sources include:
a) the emitted GHG due to the production of engineering materials, especially cement and steel;
b) the consumed fossil fuel for transporting materials; and
c) the consumed energy for digging, water extraction, concrete mixing (fossil fuels and electricity).

According to the methodology articulated in the "Provincial GHG Inventory Compilation Guidelines", the equation to evaluate total GHG emission of specific engineering measures is as follow:

$$E = \Sigma\Sigma\Sigma\left(EF_{i,j,k} \times C_{i,j,k}\right)$$

where:
E: GHG emission,
EF: emission factor,
C: amount of a given material or energy source used,
i: indicates land consolidation engineering measures,
j: indicates materials or energy sources,
k: indicates techniques or technologies.

Then, the equation for the reduction potential of an ecological measure is:

$$E_r = E_b - E_p$$

where:
E_r: net GHG emission reduction due to adoption of an ecological measures (t CO_2),
E_b: GHG emission of an engineering measure in conventional LC projects,
E_p: GHG emission of an ecological measure.

Due to the limited length of the paper, the detail calculation procedures of GHG emission volumes of the baseline condition and the pilot project were left out; the following evaluation mainly presents the end results of comparison between the conventional and ecological measures.

3.2 Evaluation of Carbon Emission Reduction Potentials

According to aforementioned standards and methods, the study evaluates the GHG reduction effects of the ecological LC project from three aspects:

3.2.1 Evaluation on the General Status of Carbon Emission Reduction

In general, comparing to the average of carbon emission levels of different engineering measures applied in conventional LC projects in Hunan Province, the total GHG reduction potential of the studied ecological LC project is 275.67 tons CO_2, which means a 0.99 ton reduction per hectare of farmland in the project area. The reduction potential of each ecological measure is listed in Tab. 3.

Generally, the ecological measures applied in irrigation and drainage system as well as ponds and river have reduced GHG emission in different extents. Whereas the clay-bound gravel surfaced field roads has slightly increased the GHG emission than the conventional gritstone surface by 0.84 ton in total, and 0.17 ton per kilometer in average.

From the aspect of carbon sources, there are mainly two reasons of GHG reductions in the construction process of the pilot project: a) reduced GHG emissions due to the savings in material use, especially cement and steel; b) reduced carbon emission due to the savings of energy use in ecological engineering measures, mainly from the savings of fossil fuels and electricity consumed for material transportations, mechanical water extraction and concrete mixing. From the data of the pilot project, 265.23 tons or 96.21 % of reduced CO_2 came from the savings from material use, whereas 10.44 tons or 3.79 % of reduced CO_2 came from the saving of energy consumption. The savings of material are the main contributor of GHG emission reduction for the project.

3.2.2 Evaluation on Individual Ecological Engineering Measures

From the perspective of GHG reduction potentials of individual ecological engineering measures, the application of ecological measures on ditches, channels, river and ponds has reduced the emission of 276.51 t CO_2; among them, the reduction potentials of several types of channels appear to be the biggest contributor which also has the largest working loads. In total, 105.82 t CO_2 was reduced after the ecological measures were applied on irrigation channels, which takes 38.27 % of the total reduction potential. The construction of ecological drainage channels has the second largest reduction with a total reduction of 86.56 t CO_2 or 31.31 % (see Fig. 6).

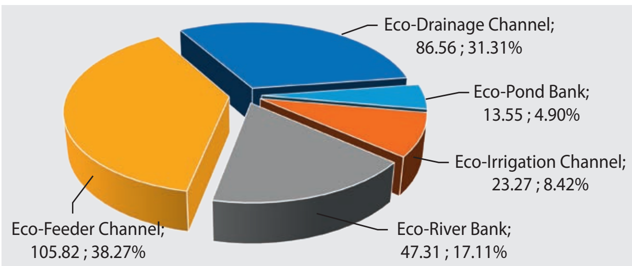


Fig. 6: GHG reduction by types of ecological measures (t CO_2)

Tab. 3: General Status of GHG Reductions of the Pilot Project*

Types	Amount (unit, m)	GHG Reduced by Saving Materials				GHG Reduced by Saving Energies					Total GHG Reductions (t CO_2)
		Cement Saved (ton)	GHG Reduced by Saved Cement (t CO_2)	Steel Saved (ton)	GHG Reduced by Saved Steel (t CO_2)	#0 Disel Saved in Material Trans. (kg)	GHG Reduced by Saved Disel (t CO_2)	Electricity Saved by Reduced Pumping (kw/h)	Electricity Saved by Reduced Concrete Mixing (kw/h)	GHG Reduced by Saved Electricity (t CO_2)	
Ecological Ponds											13.55
Ponds	15.00	24.24	13.04			65.20	0.19	211.70	190.50	0.32	13.55
Ecological Irrigation Channels											23.27
Type II	1542.10	22.06	11.87	4.01	8.81	60.75	0.18	192.60	173.40	0.29	21.15
Type IV	154.60	2.21	1.19	0.40	0.88	6.08	0.02	19.20	17.30	0.03	2.12
Ecological River Embankment											47.31
HeXing River	1573.90	67.54	36.34	4.09	8.99	372.89	1.09	573.03	535.58	0.89	47.31
Ecological Feeder Channels											105.82
Type I	23828.15	142.02	76.41	(NA)		1032.61	3.03	1204.93	1126.16	1.87	81.30
Type II	5885.62	43.85	23.59			119.03	0.35	372.02	347.71	0.58	24.52
Ecological Drainage Channels											86.56
Type I	306.95	14.00	7.53			38.00	0.11	112.17	110.00	0.18	7.82
Type III	974.79	20.92	11.25	2.53	5.56	57.45	0.17	181.59	163.62	0.28	17.26
Type IV	1864.60	40.01	21.53	4.85	10.66	109.90	0.32	347.35	312.96	0.53	33.04
Type V	240.09	19.39	10.43		0.00	53.26	0.16	168.34	151.68	0.26	10.84
Type VI	994.17	21.33	11.48	2.58	5.67	58.59	0.17	185.20	166.89	0.28	17.60
Ecological Field Access Roads											–0.84
Type I	242.09	(NA)				11.37	0.03	5.28	14.52	0.02	0.05
Type II	528.02					24.79	0.07	2.18	31.47	0.03	0.10
Type III	2562.86					103.10	0.30	9.07	131.79	0.11	0.41
Type IV	902.76					36.32	0.11	16.56	46.42	0.05	0.16
Type V	684.81					27.55	0.08	12.96	35.39	0.04	0.12
Sum											275.67

Source: adapted from "Low-carbon Land Consolidation Guidance Documents" (Wilkes et al. 2016)

*) According to the "Provincial Greenhouse Gas Inventory Compilation Guidelines", the emission factor for cement is 0.538 kg CO_2/kg, for #0 diesel is 2.930 kg CO_2/kg and for electricity is 0.801 kg CO_2/kWh. Data for the parameters for steel production in the "Provincial Greenhouse Gas Inventory Compilation Guidelines" could not be obtained and used to estimate an emission factor for steel production. Therefore, we use data from a published research (Liu 2010) which reports that the BF/BOF process has an emission factor of 2.198 t CO_2/t steel.

3.2.3 Reduction Potentials per Unit of Ecological Measures

From the perspective of reduction potential per unit, the design of the ecological drainage channel type V could reduce CO_2 emission by 45.17 kg CO_2 per meter, as the most efficient GHG reducing measure, following by the ecological drainage channel type I with the reduction potential of 25.48 kg CO_2 per meter. Other types of ecological drainage channels show GHG reduction potential to different degrees (see Fig. 7).

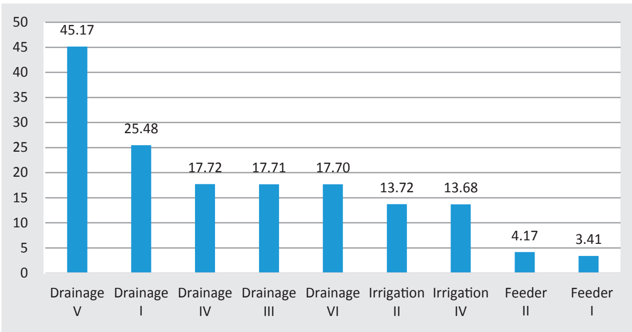


Fig. 7: GHG reduction potential per unit by types of channels (kg CO_2/m)

3.3 Financial Feasibility of Ecological Measures from a Low-carbon Perspective

Most of ecological measures achieve savings of material, energy consumption and labor which not only demonstrate the advantages to the conventional LC projects in terms of ecological effects and GHG reductions, but also exhibit cost-efficient effects or better financial feasibility as well. Comparing to the conventional measures, other than the clay-bound gravel road design has slightly increased the construction costs in comparison to the gritstone design, all the other ecological measures save construction costs between CNY 2200 to 5700 while reducing almost one ton CO_2 at the same time. Four types of ecological drainage channels are the most cost-to GHG saving designs, among them the Fig. 8: Cost Savings due to Low-carbon and Ecological Measures (CNY/t CO_2, CNY/ha) ecological drainage channel type I could reduce construction cost to 5776 CNY per ton of CO_2 reduced (Fig. 8).

From the perspective of individual engineering measures, compared to conventional measures, ecological measures reduce unit costs by about 17 % on average (minimum 4 %, maximum 57 %). The right-hand axis in Fig. 8 shows the construction cost savings per hectare for selected ecological measures. Apart from clay-bound gravel roads (construction costs of which were CNY 8 to 10 per meter higher than for conventional road surfaces), all measures reduced construction costs per unit, with cost reductions for ponds and irrigation channel type IV relatively more limited at CNY 8 to 17 per ha, while other measures can realize cost reduction of between CNY 160 to 750 per ha.

The analysis on financial feasibility provide a promising prospect for promoting low-carbon and ecological LC to a wider range. As most of the ecological measures are cost saving in comparison to the conventional ones, it means, on the one hand, the low-carbon and ecological LC measures could be adopted within the existing unit area investment standards employed in State-funded LC projects. On the other hand, for a given level of investment per hectare, the saved costs can finance additional activities with eco-environmental benefits. For example, appropriate design of LC activities at landscape

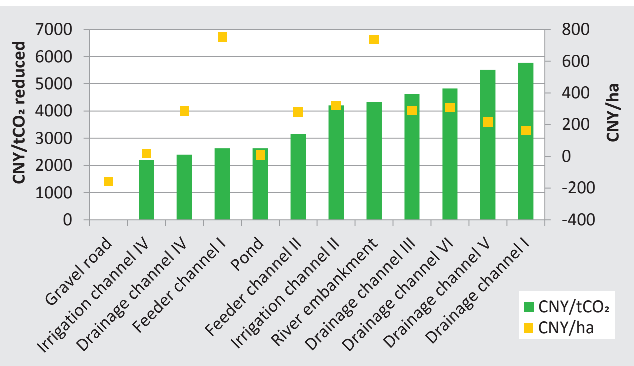


Fig. 8: Cost savings due to low-carbon and ecological measures (CNY/t CO_2, CNY/ha)

level incur additional costs in site surveys and design. Or, because there are numerous ways to address diverse ecological needs within a given project area and its surrounding region, the savings could be used to more systematically address ecological needs at the project and wider scales. In this manner, an ecological benefits of low-carbon approach can further maximize the benefits of ecological land consolidation projects.

4 Findings and Conclusions

Based on reviews of recent researches on the related subjects, this study focuses on discussing the low-carbon effects of ecological engineering measures applied in LC projects through comparative analyze the GHG emissions between the conventional and a ecological LC project. The following findings and conclusions could be draw from the study:

- Currently, the major GHG emissions in land consolidation projects that could be monitored, evaluated and controlled with agreeable accuracy, are mainly from the production and transportation of engineering material as well as the energy consumption during the construction process.
- Based on the case study, the savings of engineering materials during construction process of LC projects has the largest potential in GHG reduction. Comparing to the conventional engineering measures, the material savings due to the application of ecological measures on irrigation and drainage channels, ponds and river embankments could greatly reduce GHG emission.
- From the cost-efficiency perspective, most of the low-carbon and ecological engineering measures applied in the studied LC project have lower construction costs than the conventional measures in the region, which indicate a promising potential for wider adaptation.

To sum up, the low-carbon and ecological land consolidation highly conforms with the country's new development strategy of "promoting ecological progress" and represents the integration of ecological protection as one of the fundamental principles of land consolidation in China, which is also a advancement in pursuing the maximization of overall effects, namely: economic, social and ecological effects of land consolidation.

As the studied project has been just finished for only a short period of time, the evaluation of GHG emission reduction potentials can only focus on the major ecological engineering measures applied, the long term ecological and GHG emission effects still need further observations. Meanwhile, all the findings and conclusions are drawn based on the data of a single land consolidation project in Hunan Province, further studies are necessary to discuss the adaptation and application potentials in other regions or to land consolidation projects with different engineering components.

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