Coal, Water, and Grasslands in the Three Norths

August 2019

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

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Executive summary

Purpose of the study: This study aims to quantify and characterize the relationship between coal plant water withdrawals and their effect on grassland carbon sequestration in the Three Norths region of China.

Genesis of the study: China's Three Norths region—the Northeast, North and Northwest regions—is an important area of grassland husbandry and energy production. Coal mining and coal power production in the Three Norths poses the problems due to inadequate water supply and excessive water intake. As grassland and animal husbandry also require large amounts of water, the region's ecosystem, climate, and geology constitute a complex "coal-water-grassland" system. Existing research on the coal industry's impact on grassland focuses on coal mine pollution and its influences on regional grassland ecology.[1] Few studies attempt to quantify the water consumption of coal industry and its potential impact on grassland carbon.

Grasslands in China play a major role in the total carbon fixing worldwide. Grasslands cover approximately 25% of China's land area. China's grasslands are estimated to contain 8% of the world's soil organic carbon and 16% of China's soil organic carbon.[2] Synthesis of various studies suggests that China's 355 million hectares of grassland ecosystems store around 31.5 Pg of carbon, several orders of magnitude greater than China's approximately 10 Gt/year of CO_2 emissions.[3] China's Three Norths region is home to a 40% of China's coal plant capacity, as well as to 41% of China's grassland. Most of the region suffers from high levels of water stress, and prior studies have noted the high numbers of coal plants located in water stress regions of the Three Norths. Hence, it is important to understand whether coal plant water withdrawals are affecting carbon sequestration of the region—which would represent a double whammy for the climate from both emissions and carbon fixing.

Main findings: Coal plant water withdrawals do not appear linked to grassland carbon sequestration in the Three Norths. This finding rests on several factors, some of which are quantified in this report, others of which require further research:

- From 2000 to 2015, the carbon sequestered in grasslands of the Three Norths has increased in total (by 18.7%), even as the area of grassland has declined by 0.9%, due to rising carbon fixing per unit area.

- During this period, raw coal production in the region has increased 457% and coal power generation has increased 272% to 1,575 TWh.

- Coal plants, coal mining, and related water withdrawals appear unrelated to grassland health in the region. Coal plant water withdrawals and grassland irrigation from surface or groundwater are too small a portion (4-5%) of regional water consumption to come into competition—and the same holds true within provinces. Only 10% below of China's grassland is irrigated.

- Precipitation changes may account for most of the increase in grassland carbon sequestration in the Three Norths. An analysis of NPP changes and precipitation changes by map coordinate suggests a modest relationship, though further research may be needed.

- It is interesting to note that NPP and coal plants are both heavily concentrated in regions with the highest water stress—with over 50% of each in water catchments of high or extremely high water stress. Relatively speaking, however, coal plants are relatively more concentrated in such regions compared to NPP. Hence, coal power production may be more vulnerable to water stress than grassland NPP.

- As China phases out coal power, the impact of coal-related water consumption on grasslands should decline further. In this report, we quantify coal plant water withdrawals in the Three Norths based on China National Renewable Energy Centre projected power generation by coal in the Three Norths by 2030 and 2050, finding that coal water consumption should peak around 2025, and total Three Norths coal industry water consumption in 2050 should be under half that of 2015.

Attribution and authorship: This study was initiated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, which is the implementing agency for the BMWi-funded project German Energy Transition Expertise for China, in partnership with the China National Renewable Energy Centre.

- The Institute of Geographical Sciences and Natural Resources Research of Chinese Academy of Sciences (CAS) completed the bulk of the research, including primary analysis, findings, and charts of grassland locations and NPP. CAS authored the Chinese report 中国“三北”地区煤炭能源开发对草地牧业及草原碳汇的影响. Primary researchers: Sun Zhen, PhD; Jia Shaofeng, Head of Water Resource Research Department, Professor; Lv Aifeng, Associate Professor; Xiang Xiaozhi, PhD; Liu Wenhua, Associate Professor.

- The World Resources Institute (WRI) provided data and analysis related to coal plant locations and water withdrawals. Primary researchers: Fu Xiaotian, China Water Lead; Wang Jiao, Researcher of China Water Program.

- GIZ used coal power generation forecasts and modeling results from the China Renewable Energy Outlook 2018 to extrapolate future water usage in the Three Norths. This English summary report was completed by GIZ. GIZ summary report authors and researchers: Anders Hove, Project Director; Wang Xinnan, Technical Advisor; and GIZ research interns Huang Yuqiao, Xiang Qixin, Zhang Jiaxuan and Wang Zilin. Translation provided by GIZ research interns Wang Shuo and He Likun.

1. The Three Norths region features high water-stress, high coal use, and abundant grasslands

China's Three Norths region—the Northeast, North and Northwest regions in China—is an important area of grassland carbon sequestration and coal energy production. Given ongoing concerns about water consumption by the coal sector, it is surprising that research on the coal industry's impact has typically not addressed the overlap of the coal sector in China with the nation's grassland resources. China's 355 million hectares of grassland ecosystems store around 31.5 Pg of carbon, several orders of magnitude greater than China's approximately 10 Gt/year of CO_2 emissions.[4] China's Three Norths region is home to a 40% of China's coal plant capacity, as well as to 41% of China's grassland. Most of the region suffers from high levels of water stress.

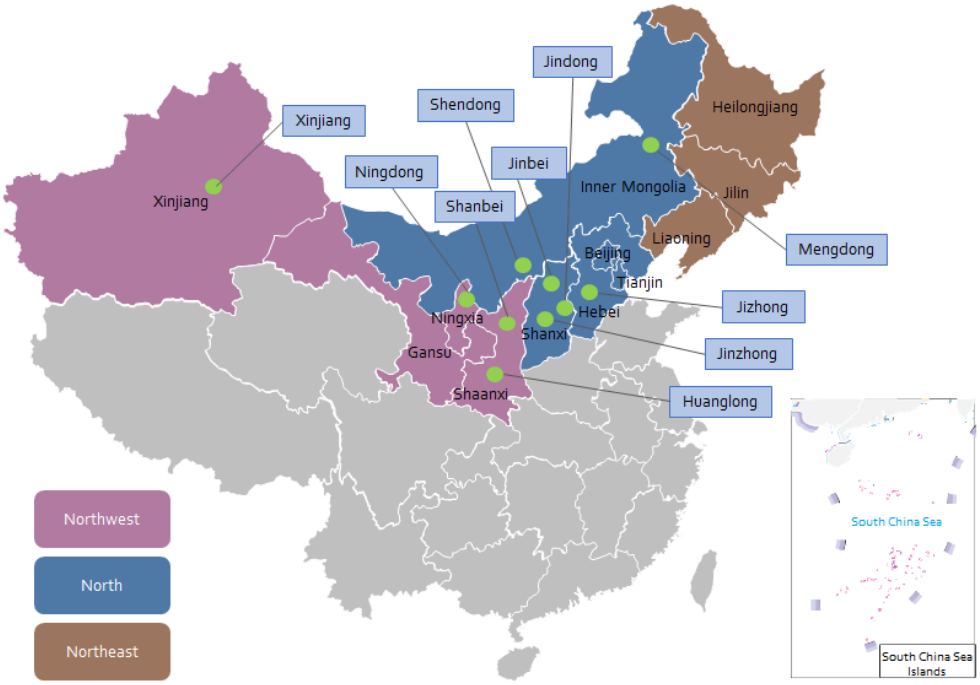
In this section, we review statistics of the coal industry in the Three Norths, coal industry water consumption, grassland area, grassland biomass density, and grassland carbon sequestration. The study is essentially an overview of the interaction between these factors at the broadest scale, attempting to characterize the potential interaction between the coal industry's activity in the area with regional trends for grassland carbon sequestration.

Overall, on the basis of this correlational overview, we find that coal plant water withdrawals do not appear linked to grassland carbon sequestration in the Three Norths. This finding rests on several factors, some of which are quantified in this report. From 2000 to 2015, the carbon sequestered in grasslands of the Three Norths has increased in total (by 18.7%), even as the area of grassland has declined by 0.9%, due to rising carbon fixing per unit area. Coal plant water use accounts for a relatively small share of regional water consumption, and most grassland in the region is not irrigated—hence, water withdrawals play little role in grassland health in the region.

1.1 The Three Norths is China's main base for coal production, coal powerand coal chemicals

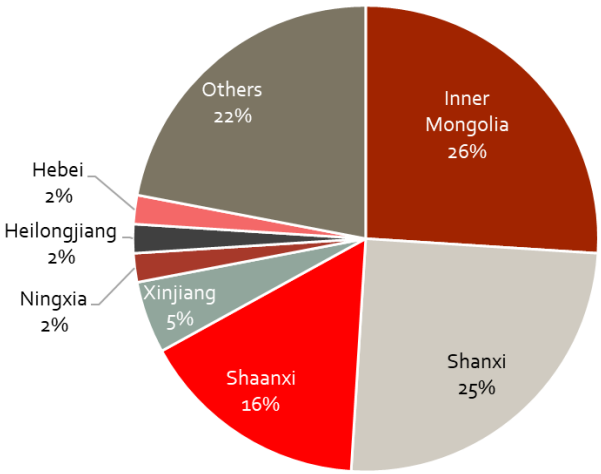
Coal has highest proportion in China's primary energy consumption. In 2016, China consumed 2,703 million tonnes of coal equivalent (Mtce) of coal, accounting for 62% of the nation's primary energy consumption, and representing 50.7% of world coal consumption that year.[5] The coal industry includes coal mining and preparation, coal power and the coal chemical industry. China has 14 coal bases with coal production more than 100 million tonnes, 10 of which are located in the Three Norths.[6] From 1991 to 2016, the raw coal production of the Three Norths showed a rising trend. Raw coal production reached a maximum of 3.08 billion tonnes in 2012, which is about six times the coal production in 2000. Since then, production has gradually fallen back to 2.66 billion tonnes in 2016, accounting for 80% of the national total production.[7]

Major coal bases in the Three Norths



Source: China Academy of Sciences (CAS), December 2018

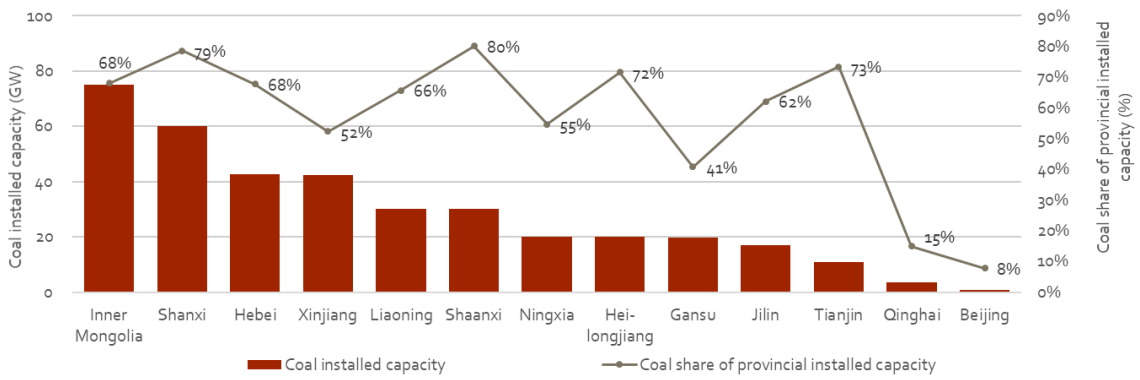
2016 Coal production by province



Source: National Bureau of Statistics of China (NBS), accessed March 2019

The Three Norths region also relies heavily on coal for power production. In 2016, the region hosts more than 1,600 coal power plants, accounting for more than one-third of the national total. Regional total installed capacity of coal power reached 372 GW, accounting for about 40% of the national total, [8] and the region represented 41.5% of national electricity consumption in that year.[9] Coal power installed capacity accounted for 62% of the total installed capacity of the Three Norths region, compared to 54% in other regions. The average proportion of coal for power of the total coal consumption of each province in the Three Norths reached 40%.[10] Meanwhile, many new coal power plants are under construction in the Three Norths.

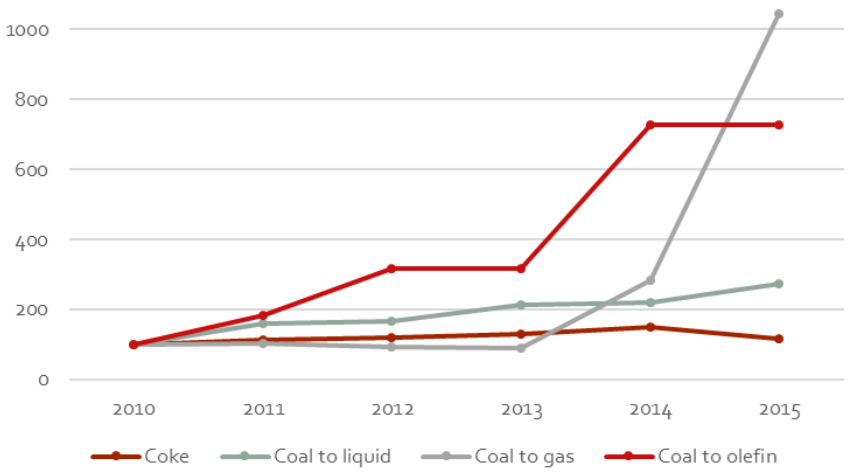
2016 Coal power installed capacity (GW) and proportion in the Three Norths, by province



Source: data of coal installed capacity is from Electric Power Planning & Engineering Institute (EPPEI), July 2017; data of coal share of provincial installed capacity is from China Electricity Council (CEC), August 2017

At present, China's coal chemical industry includes both the traditional and modern coal chemical industries. The traditional coal chemicals industry mainly refers to the coal-coke industry chain, while the modern coal chemical industry refers to coal processing and energy transformation industry that uses coal as raw material to produce other fuels such as methanol as well as basic chemical products. After 2010, due to the policy of environmental protection and production restrictions, the development of traditional coal chemical industry has experienced restrictions on new developments.[11] In 2015, coke production was 265.17 million tonnes—16% higher than in 2010, but still 22% lower than the peak in 2014.[12] In contrast, the modern coal chemical industry has developed rapidly, with coal-to-liquid, coal-to-gas and coal-to-olefin production continuing to grow. By 2015, coal-to-liquids output reached 825,600 tonnes, or 173% higher than 2010; coal-to-gas reached 1.85 billion m^3, or 946% higher than in 2010; and coal-to-olefins output reached 3.32 million tonnes, 629% above that of 2010.[13]

2010-2015 coal chemicals yield trend in the Three Norths



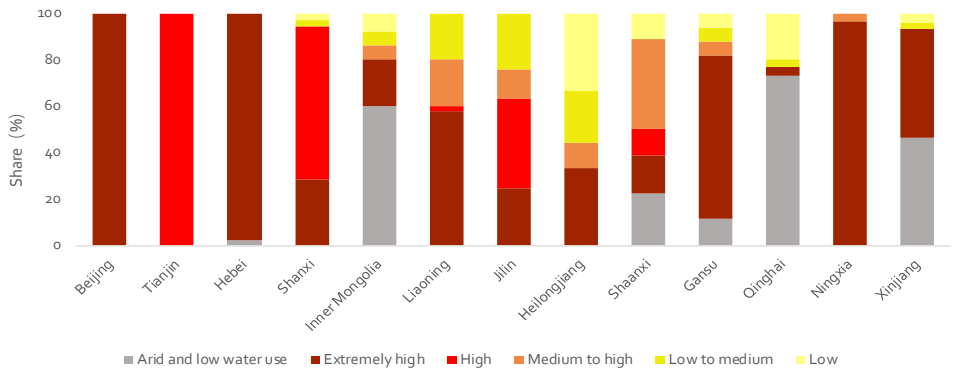
Note: The calculation is based on the output of the product in 2010. The corresponding values for the year are multiplied 100 by the ratio of the output of the year to the output of that in 2010. Source: data of coke, coal to liquid and coal to gas is from NBS, accessed in March 2019; data of coal to olefin is from Petroleum and Chemical Industry Planning Institute, October 2017

1.2 The Three Norths faces high water stress

Various studies have shown that China's Three Norths region suffers from high water stress. For example, the World Resources Institute (WRI) estimated 2015 baseline water stress among the watersheds of the Three Norths using various factors. Baseline water pressure is calculated by dividing the annual water withdrawal (domestic, industry and agriculture) by the average annual available surface water resources. In some watersheds with water withdrawal and available surface water resources below a minimum threshold, WRI could not characterize water stress.[14]

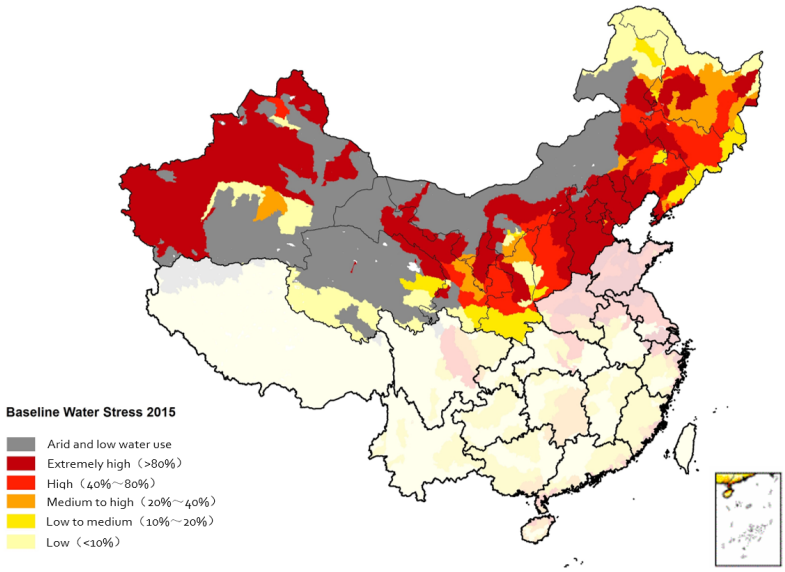
The climate of the Three Norths is arid and semi-arid with low humidity and rainfall.[a] Based on the WRI map of water stress, all provinces in the region except for Shaanxi, Heilongjiang, Inner Mongolia, Qinghai, and Xinjiang have high or extremely high water stress in more than 70% of their land area. In Beijing, Hebei, Ningxia, Gansu, and Xinjiang, almost all of the non-arid & low water use land experiences extremely high water stress. More than half of the area of Qinghai and Inner Mongolia is arid and has low water use.

2015 percentage of baseline water stress level in each province of the Three Norths



Source: World Resources Institute (WRI), August 2018

2015 baseline water stress in the Three Norths



Source: WRI, August 2018

a In China, arid and semi-arid climates are collectively referred to as arid and semi-arid regions. The semi-arid climate is also called grassland climate. Its annual precipitation is less than the annual evaporation. The arid climate is also called desert climate. It is characterized by dry air and little or no rain all year round. Its daily temperature changes can reach above 50 °C.

1.3 Water consumption of the coal industry and irrigation of grassland is relatively low

From 2010 to 2015, the total water consumption in the Three Norths first increased, and then decreased. In 2015, the total water consumption of the Three Norths was 202.48 billion m^3, which is lower than the water red line of 206.57 billion m^3.[15] The total water consumption in these provinces includes agricultural water, industrial water, domestic water, and ecological and environmental water. Water used in the coal industry is classified as part of the industrial water use category. Grassland water—that is, irrigation water used for sustaining grasslands—is classified as agricultural water.

2010-2015 water consumption statistics in the Three Norths

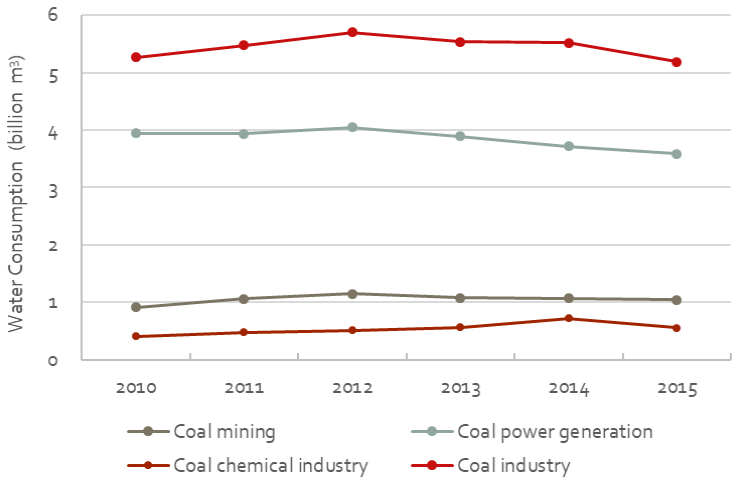
Unit: billion m^3	2010	2011	2012	2013	2014	2015
Total	192.92	198.09	203.80	204.39	203.55	202.48
Coal industry	5.27	5.48	5.70	5.54	5.52	5.19
Grassland irrigation	2.25	2.54	2.84	3.10	2.73	3.40

Source: CAS, December 2018

According to data from CAS, from 2010 to 2015, the total water consumption of the coal industry in the Three Norths has fluctuated within a narrow range of less than 10%. 2015 coal industry water consumption was lower than 2010 consumption. The water consumption of the coal industry in all provinces represents under 5% of provincial water use in most provinces, and under 10% in all provinces. The water consumption proportion of the coal industry has been decreasing since 2013 and declined to just 2.56% of total Three Norths water consumption in 2015. Viewed from the provincial level, the average water consumption proportion of 2010 to 2015 of coal industry in four provinces accounted for the largest proportion, reaching 9.29% in Shanxi, 7.36% in Jilin, 4.55% in Inner Mongolia, and 4.18% in Shaanxi. Xinjiang coal industry water consumption accounted for the smallest proportion of coal industry water use proportion, at 0.43%.[16]

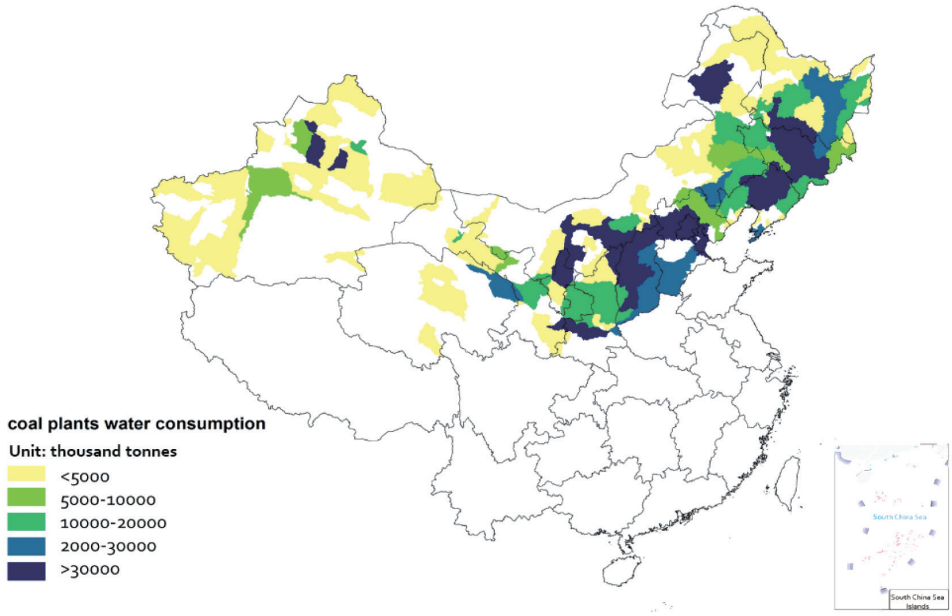
From 2010 to 2015, the average proportion of total coal industry water consumption for each coal sub-sector was 70.76% for coal power, 19.31% for coal mining and preparation, and 9.93% for the coal-chemical industry. Coal power is the largest water consumption sector in the coal industry.[17] As the chart below shows, these proportions have remained relatively stable, and there is no clear trend of increasing or decreasing water consumption by the coal industry or its subsectors during this period.

2015 baseline water stress in the Three Norths



Source: CAS, December 2018

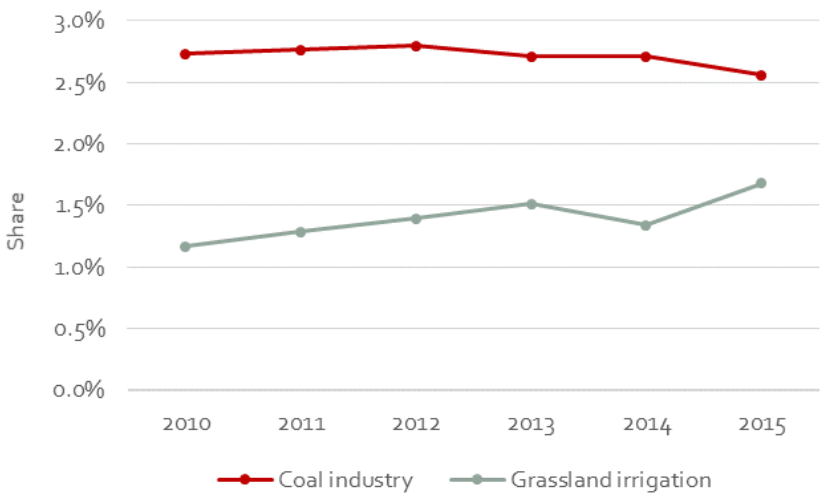
2015 coal plant water consumption in the Three Norths, by water catchment



Source: WRI, August 2018

Water consumption for grassland irrigation also accounts for a small share of water use in the Three Norths. From 2010 to 2015, the proportion of grassland irrigation water also remained fairly stable as a proportion of provincial water consumption. The grassland irrigation water consumption in each province accounts only for a small proportion of total water consumption. The highest proportions of irrigated grassland water consumption are in Xinjiang (3.99% in 2015), Inner Mongolia (4.16%), and Qinghai (1.71%). The proportion of irrigated grassland for other provinces was below 1%.[18]

2010-2015 proportion of coal industry and grassland irrigation in the total water consumption in the Three Norths



Source: CAS, December 2018

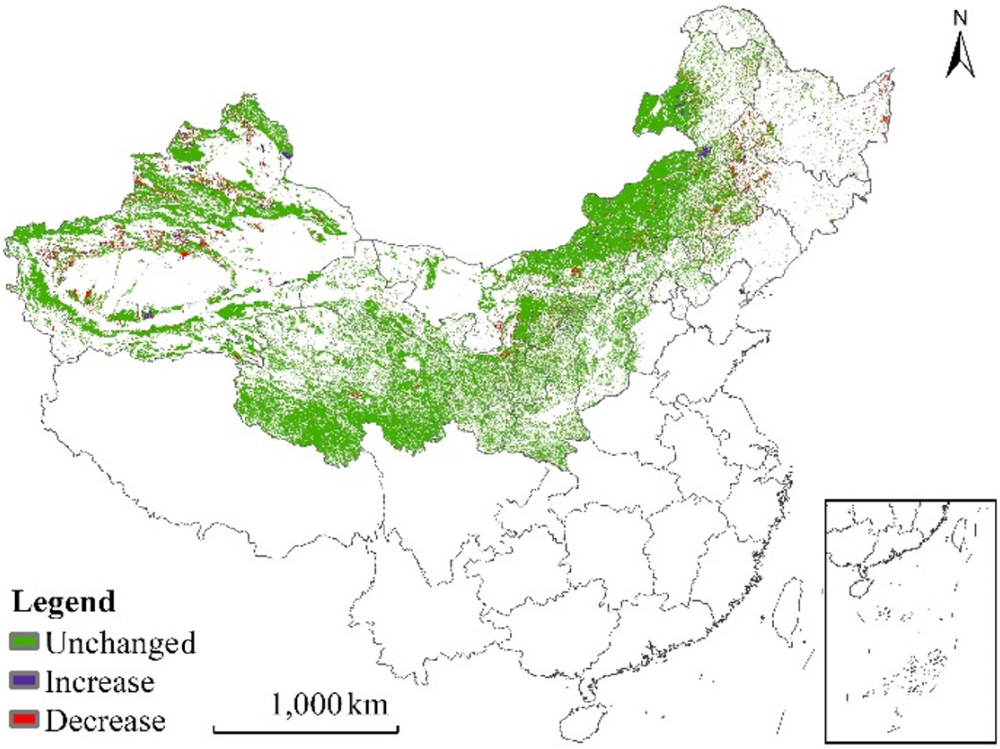
1.4 Grassland area and productivity showed several trends during 1980-2015

Grassland area

Grassland ecosystems play a key role in carbon sequestration and terrestrial carbon cycle. They are important carbon sinks. China's grasslands are estimated to contain 8% of the world's soil organic carbon and 16% of China's soil organic carbon. According to the assessment report issued by the Intergovernmental Panel on Climate Change (IPCC), 1 hm of grassland can fix 1.3 tonnes of carbon per year, which is equivalent to reducing CO_2 emissions by 6.9 tonnes. China's grassland area is about 4 million km^2, which captures about 520 million tonnes of carbon per year, equivalent to a reduction of 2.76 billion tonnes of CO_2 per year. It accounts for 30% to 50% of the national carbon emissions.[19] According to the National Bureau of Statistics, the grassland area of the Three Norths accounted for 44.2% of the national natural grassland area, and the Three Norths has 40.9% of China's total grassland area.[20] Irrigated grassland in the Three Norths accounts for less than 10% of the total grassland area of the region. Grassland area varies greatly by province: Inner Mongolia, Xinjiang and Qinghai have the largest grassland area, 375,000 km^2, and together account for 78.7% of the total grassland area of Three Norths.

From 1980 to 2015, the grassland area of the Three Norths provinces decreased. The grassland area decrease was highest in three provinces of Northeast China: Jilin's grassland area decreased 36.6%, Tianjin's 28.2% and Heilongjiang's by 21.2%. The grassland area declined less than 1% in Hebei, Qinghai, Shaanxi, Gansu and Shanxi. However, the rate of change in grassland area in the Three Norths has stabilized since 2000. Compared with that of 2000, the grassland area in the Three Norths decreased by 0.9% in 2015. The range of change is around ±3% in areas other than Tianjin. Except for Jilin, the grassland area of all other provinces has fallen to the lowest level since 1980.[21]

1980-2015 change of grassland area spatial distribution map in the Three Norths



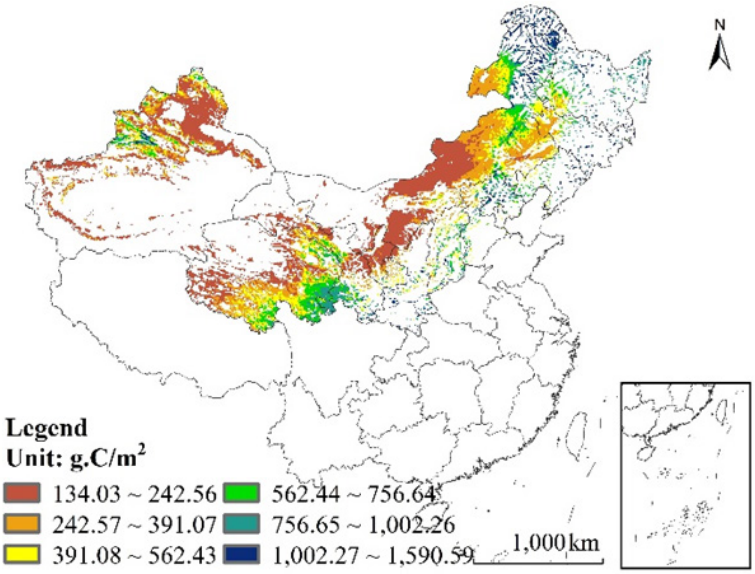
Source: CAS, December 2018

Total biomass density

Total biomass density of grassland consists of aboveground biomass density and underground biomass density. From 1982 to 2015, the total biomass density of the Three Norths region fluctuated within a fairly narrow range. Across the Three Norths, biomass density has a broad range, from 134.03 to 1590.59 grams of carbon (g.C)/m^2. The average total biomass density of the Three Norths from 1982 to 2015 was 397.60 g.C/m^2, in which the average underground biomass density was 321.48 g.C/m^2, 4.22 times the above ground biomass density. In 2015, total biomass reached 724.95 T.g.C, showing an average annual increase of 0.30% compared to 2000. The spatial distribution of biomass is greatly affected by topography and climate.[22] Except for the northern part of Xinjiang, the total biomass density of the Three Norths increases from west to east, and in the central region it shows a tendency to increase from north to south.

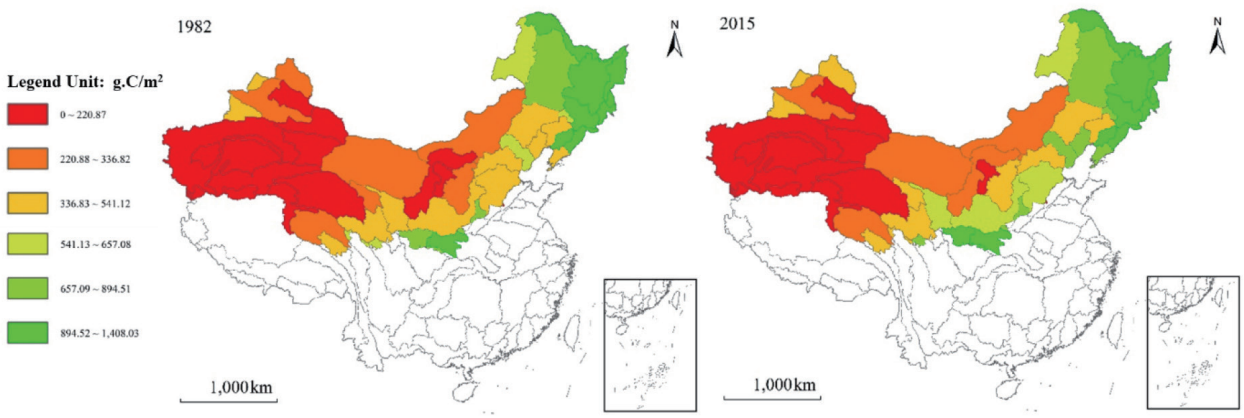
The trend at the catchment level showed a similar pattern, in that the increase or decrease in total biomass density varied from west to east: Between 1982 and 2015, the total biomass density of the four catchments in the northwestern region decreased, with the highest decline reaching 23.99 g.C/m^2. The North region saw an increase of between 100-166 g.C/m^2, while the Northeastern region reached 200 g.C/m^2.

1982-2015 spatial distribution map of average total biomass density of grassland in the Three Norths



Source: CAS, December 2018

1982 and 2015 spatial distribution map of total biomass density of glassland in each catchment of the Three Norths



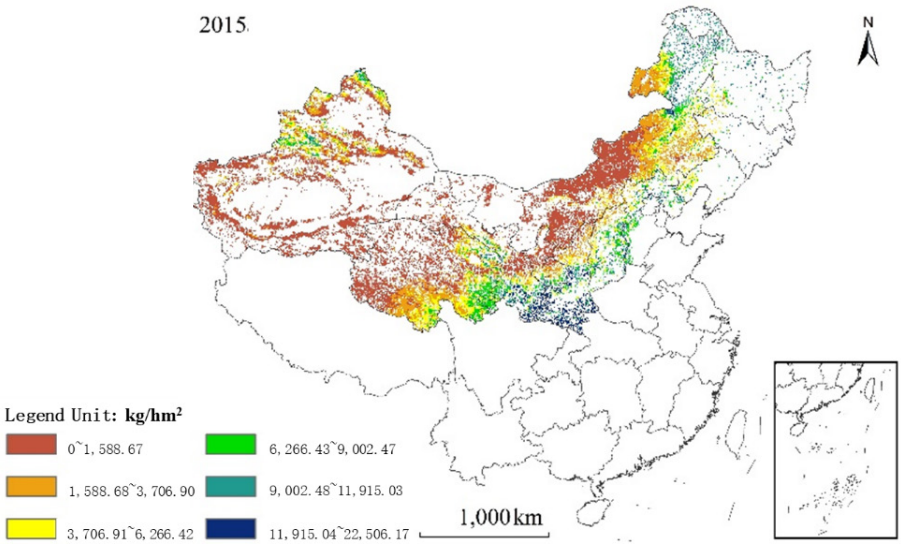
Source: CAS, December 2018

Total and per unit area grass yield

From 1982 to 2015, the total grass production and grass production per unit area of the Three Norths experienced a variety of trends, with overall grass production increasing towards the end of the period. By 2015, the total grass production and grass production per unit area reached their maximum, with 573 million tonnes and 329.67 t/km^2. From 1982 to 2015, the average total grass production varied widely among provinces. The largest provinces, Inner Mongolia, Xinjiang and Qinghai, in total accounted for 59.60% of all grass production in the Three Norths. Ningxia, Liaoning, Jilin, Beijing and Tianjin have the smallest annual grass production, each accounting for only about 1%.

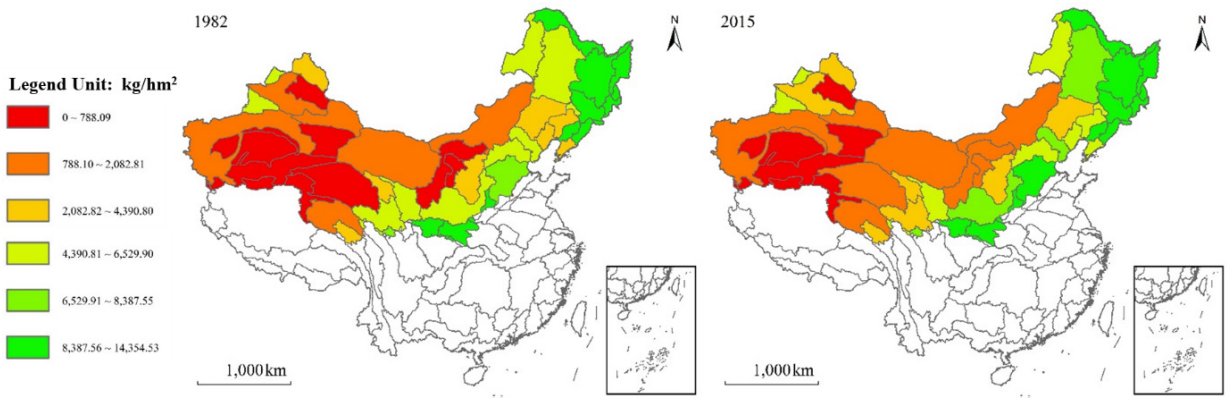
The trend of grass yield per unit area is similar to the trend for total grass yield. Except for the northern part of Xinjiang, the grassland yield per unit area of the Three Norths increased from west to east and the central region showed a trend of increasing from north to south. Between 2000 and 2015, the amount of grass per unit area in the entire region changed little, and the area of regions experiencing increase and decrease was basically the same. The trend of grass yield per unit area is different in different catchments.

2015 spatial distribution map of grass yield per unit area in the Three Norths



Source: CAS, December 2018

2015 Spatial distribution map of grass yield per unit area in each catchment of the Three Norths



Source: CAS, December 2018

Carbon sequestration capacity

Net Primary Productivity (NPP) can be used to assess the carbon sequestration capacity of grassland. The total amount of NPP is equal to the product of the unit area NPP and the grass area for which NPP is greater than or equal to zero. From 2000 to 2015, the total amount of NPP in the Three Norths showed an alternating pattern of increase and decrease, reaching a maximum of 269.68 T.g.C in 2015, compared to an average annual increase of 1.25% in 2000.

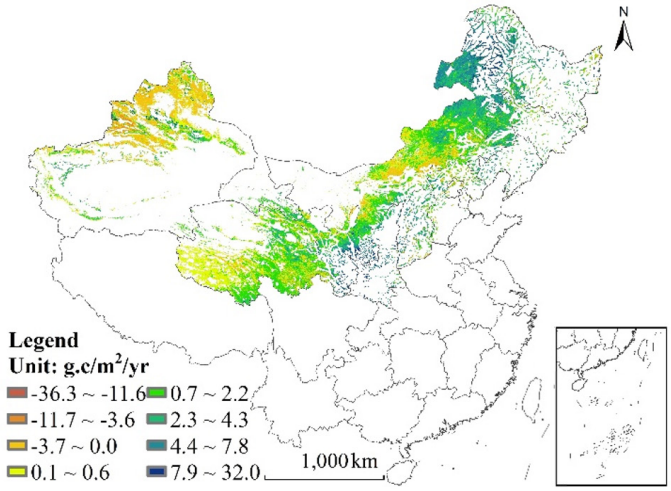
The grass area of NPP in each province shows a decreasing trend, reaching 1.37 milliom km² in 2015. Compared with 2000, the annual average decline was 0.87%. Between 1982 and 2015, per unit area NPP in regions other than Shaanxi and Qinghai generally showed an increasing or steady trend. The NPP per unit area of the Three Norths reached a maximum of 197.02 g·C/m² in 2015.The spatial distribution shows an increasing trend from northwest to southeast. The NPP per unit area in all northwestern provinces are less than 200 g.C/m²; the central and eastern region ranges between 200-300 g.C/m²; and the northeast is greater than 300 g.C/m². Although the grassland area with NPP that is greater than or equal to zero is reduced, the grassland quality per unit area is better, and the total amount of NPP is increased. The change trend of NPP per unit area in different catchment is different.

Statistical table of carbon sequestration capacity of grassland in the Three Norths

	2000	2005	2010	2015
Area (km²)	1,380,849	1,375,355	1,375,103	1,368,829
NPP (g.C/m²)	165.94	189.42	183.86	197.02
NPP (T.g.C)	229.13	260.51	252.82	269.68

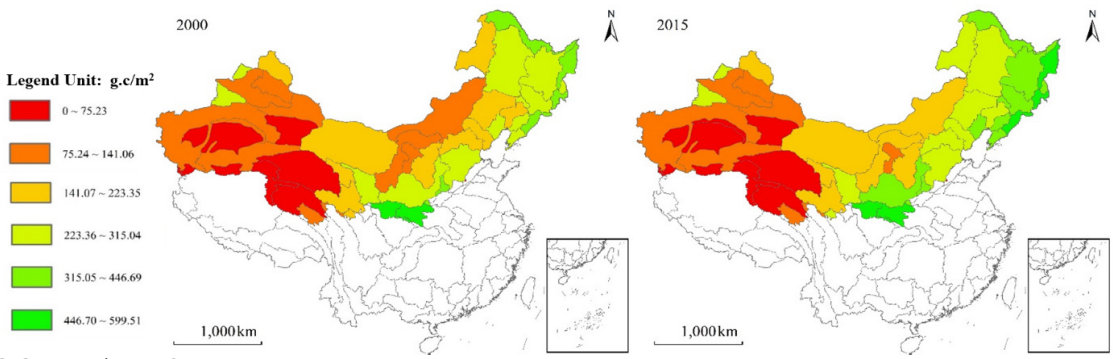
Source: CAS, December 2018

2000-2015 Annual change rate of grassland NPP in the Three Norths



Source: CAS, December 2018

2000-2015 spatial distribution map of NPP per unit area of each catchment in the Three Norths



Source: CAS, December 2018

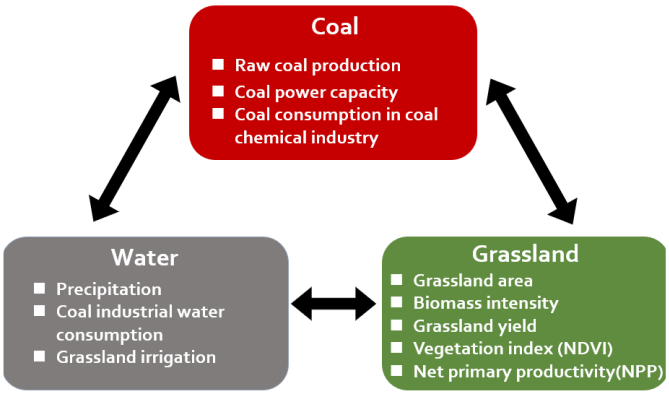
2. Water use of the coal industry appears to have minor impact on grassland in the Three Norths

As the preceding chapter has shown, coal plant water consumption accounts for a relatively small and stable share of overall water consumption in the Three Norths, whereas grassland area in the region has fallen but grassland productivity has risen somewhat. Most grassland in the region does not depend on irrigation for its development. In this section, we discuss in greater detail the factors affecting grassland productivity. Overall, the study shows that increased grassland productivity correlates moderately well with changes in precipitation. Interestingly, regions with high concentration of grassland and coal plants have seen improved grassland productivity. Although the relationships shown here do not definitively exclude the possibility of major impacts of coal plant water use on grassland in certain areas or cases, the data broadly suggest no overall relationship.

2.1 Water consumption in the coal industry has little effect on grassland irrigation

The development of the coal industry in the Three Norths influences grassland water consumption and animal husbandry through four paths. The first three paths refer to the regional impacts of coal industry development on grassland, including irrigation water, biomass, grass yield, and carbon sequestration change in time and space. The fourth path is the local impact of coal industry on the surrounding grassland ecology.

Relation path map of coal-water-grassland

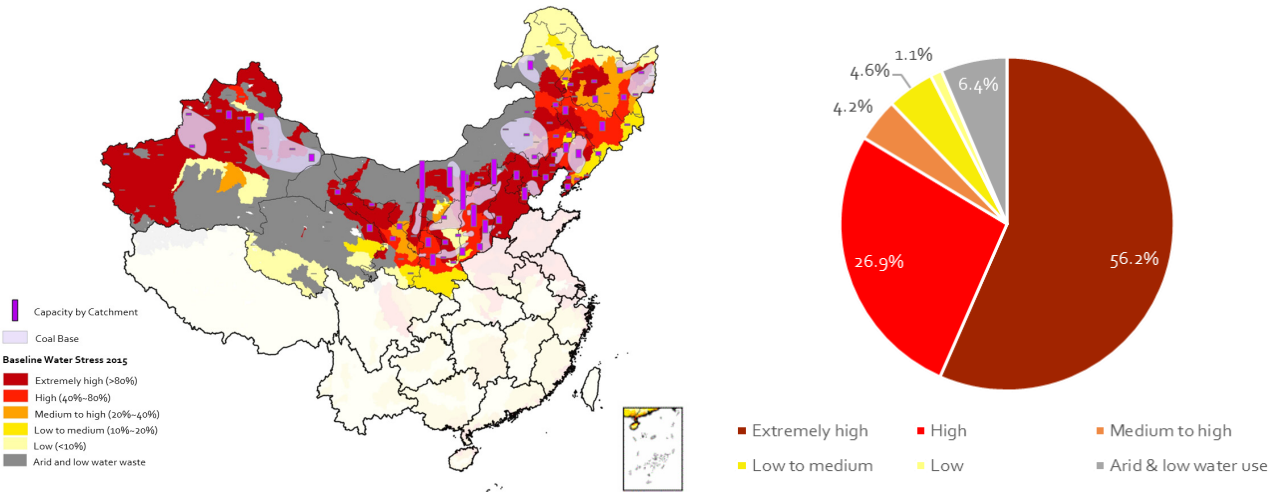


Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, April 2019

Water consumption in the coal industry has little effect on grassland irrigation. The proportion of water consumption of the coal industry and grassland irrigation in the provincial total water consumption is only 2.56% for the coal industry and 1.68% for grassland irrigation. In addition, there appears to be basically no correlation between the two. Because grassland using irrigation water only accounts for less than 10% of the total grassland area in the Three Norths, irrigation water has no measurable overall impact on grassland area, grassland carbon sequestration, or grassland animal husbandry.

53.28% of the land area in the Three Norths is arid and has low water use; 18.77% of the land area has extremely high water stress, and 3.49% of the area has high water stress. In the Three Norths, 56% of the region's total coal power capacity is installed in areas with extremely high water stress, and 27% of installed capacity is located in areas with high water stress. In catchments with high water stress, the government has issued special plans for coal industry coal power bases: water resources can be deployed in and across river catchments. Therefore, the baseline water stress does not fully reflect the availability of water for a particular catchment. The actual baseline water stress for the catchment may be less than the result shows.

2015 spatial distribution of coal mine, coal power base and baseline water stress in the Three Norths (left); Proportion of power capacity under different levels of water stress in the Three Norths (right)



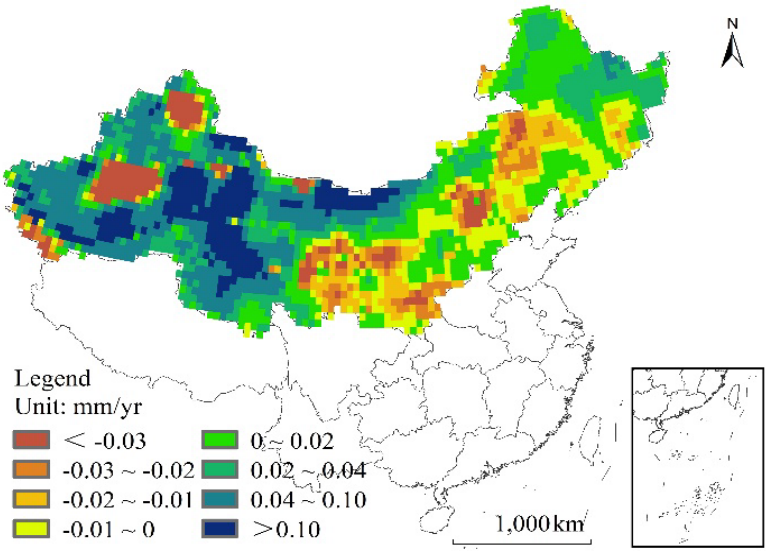
Source: WRI, August 2018

2.2 Precipitation may be main factor accounting for grassland biomass increase

From 1995 to 2015, in the Three Norths the grassland biomass and grass production increased, despite the rapid expansion of the region's coal industry during this period.

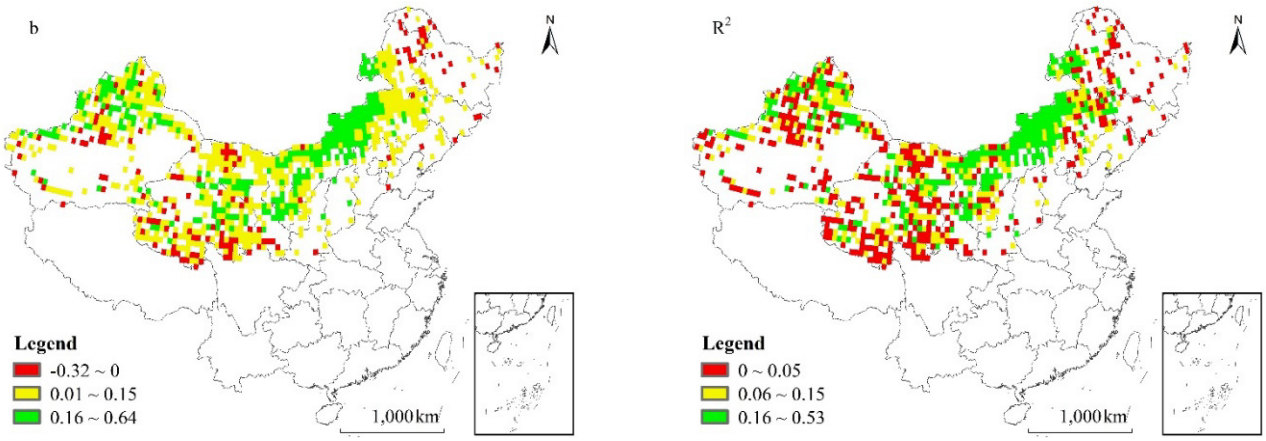
The change in grassland biomass and net primary production may be explained in part by the effects of precipitation. Though precipitation changes over the period varied by region, precipitation has generally increased, and the study shows that locational precipitation changes largely correlated with grassland biomass and NPP. From 1982 to 2015, the aggregate precipitation from January to July in northwest China increased, and in the northeast and most parts of northern China decreased. However, after 2000, precipitation from January to July in the Three Norths increased stably. The precipitation of the Three Norths and the grassland NDVI (vegetation index) showed a weak positive correlation, that is, 11% of the NDVI change of grassland is caused by precipitation. However, the correlation between the two shows significant spatial differences: it is negatively correlated in humid and semi-humid areas such as southern and northeastern part of Qinghai; in arid and semi-arid regions such as Inner Mongolia, Ningxia and Hebei, the correlation is positive.

1982-2015 Annual change rate of aggregate precipitation from January to July in the Three Norths



Source: CAS, December 2018

1982-2015 Correlation between aggregated precipitation (January to July) and maximum NDVI in the Three Norths

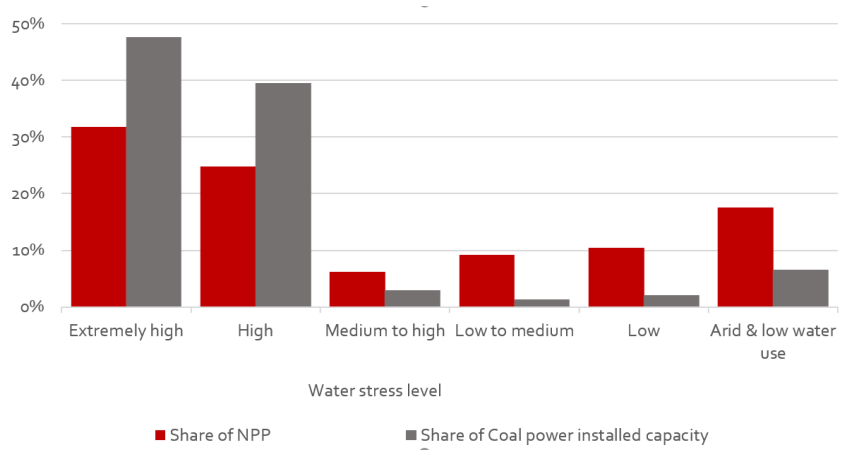


Notice: b represents regression coefficient; R^2 represents coefficient of determination. Source: CAS, December 2018

2.3 Precipitation significantly influenced grassland sequestration while use of coal didn't

The development of coal industry did not noticeably hurt grassland carbon sequestration. From 2000 to 2015, in the Three Norths the overall NPP increases, and the carbon sequestration capacity of grassland did not decrease with the expansion of coal industry. On the catchment level, changes in NPP show spatial differences in the Three Norths. For each catchment in 2015, the proportion of its NPP in total NPP in the Three Norths did not directly correlate with the proportion of its coal power capacity in the region. Some catchments with large coal power capacity also have high total NPP. The use of coal does not significantly affect the NPP of catchments.

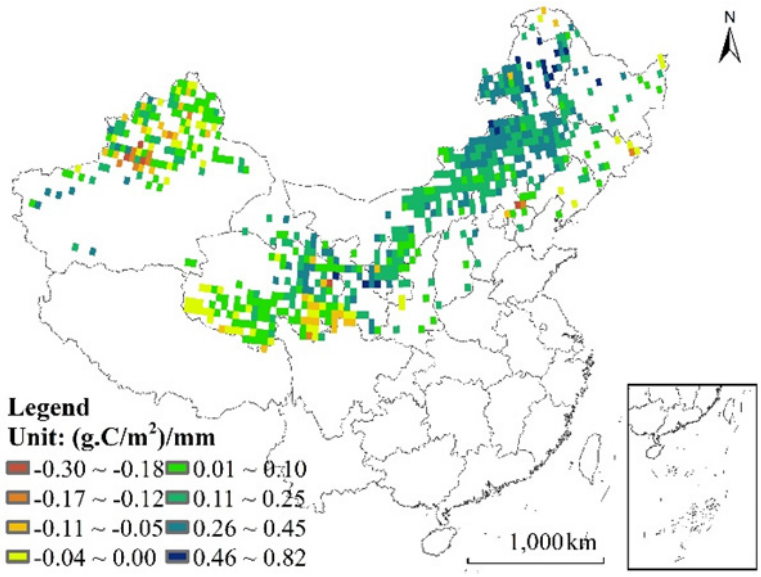
2015 Proportion of NPP and coal power capacity of catchments in the Three Norths



Source: data of coal power capacity in the Three Norths is from ENDCOAL, July 2017; data of water stress is from WRI, August 2018

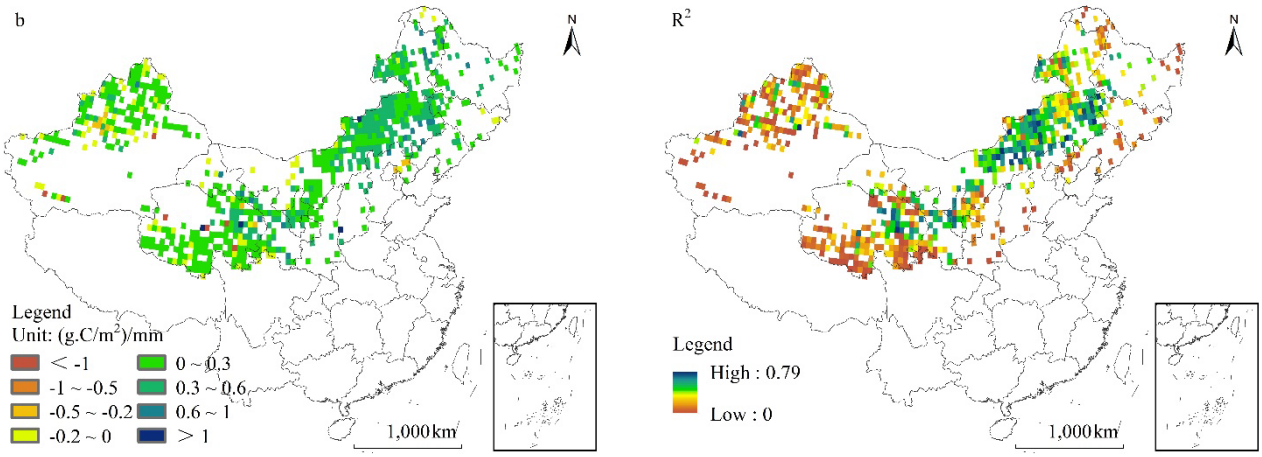
This study suggests that precipitation is the main factor that influences NPP per unit area. According to the spatial distribution of regression coefficient b, from 2000 to 2015, the NPP per unit area in most of the Three Norths provinces are positively correlated with precipitation from January to July. The areas affected sensitively by precipitation are mainly in the east and south regions, and the maximum increase rate reaches 32.0 g.C/m^2/yr. In few areas in Xinjiang, Qinghai, and Inner Mongolia, it shows negative correlation.

2000-2015 Correlation between precipitation and NPP per unit area in the Three Norths



Source: CAS, August 2018

2000-2015 Correlation between precipitation and NPP per unit area in the Three Norths



Notice: b represents regression coefficient; R^2 represents coefficient of determination. Source: CAS, December 2018

2.4 Policies encourage mines to reclaim grassland area

According to government policy, coal mines in the Three Norths must follow the principle of simultaneous industry development and environment protection. As a result of this policy, coal mining should ideally have a positive impact on the carbon sequestration of surrounding grasslands. From 1980 to 2015, in the Three Norths, the land use of coal bases increased. From 2010 and 2015, the scale of coal mine expanded rapidly. Coal mining inevitably causes pollution to land, water and air, such as surface subsidence, vegetation degradation, and river pollution.

The Chinese Academy of Sciences analyzes two restoration cases of two underground mines: the Dayan Coal Mine, in Inner Mongolia, and the Xingdong Coal Mine, in Hebei. CAS found that grassland carbon sequestration remained stable in areas surrounding the mines. In addition, after the mines were closed, mining companies are held responsible for land restoration, which includes recovery of the surrounding ecosystem. The CAS study also reports on the ecological restoration of open pit mines, such as Shengli Coal Mine, Inner Mongolia, and the ecological restoration carried out in the surrounding area, similarly showing successful restoration efforts and their impact on nearby grassland.

3. Water use of coal industry in Three Norths will increase, then decrease

According to the stated policies scenario of the China Renewable Energy Outlook 2018 (CREO 2018), fossil energy in primary energy consumption will peak in 2021, and the proportion of coal consumption in power generation and industrial sectors will continue to shrink.[23] By 2050, renewable energy will supply the majority of China's primary energy, accounting for 31.0% of total primary energy consumption, and the proportion of primary energy provided by coal will fall to 14.5% by that year.

3.1 China Renewable Energy Outlook forecasts coal production to decline, coal power to increase, then decline

For this study, we developed our own forecast of coal industry water consumption in the Three Norths based on provincial coal industry projections in the Stated Policies scenario of CREO 2018, and on several broad assumptions concerning water use in the sector. This coal industry water use projection is based on CREO's projected rate of change rate of raw coal production nationally from 2015 to 2030 and 2050, on CREO's projected coal power generation in each of the provinces in Three Norths, on CREO's projected coal consumption in coal chemical industry, and on the assumption that water consumption in each subsector of the coal industry nationally remains constant. Hence, the projection uses annual water consumption figures for 2015 to estimate the water consumption of the coal industry in 2030 and 2050. This methodology is relatively simplistic; additional data and research could allow for a more accurate projection of coal industry water consumption—for example, based on present or future consumption at individual facilities or in specific counties.

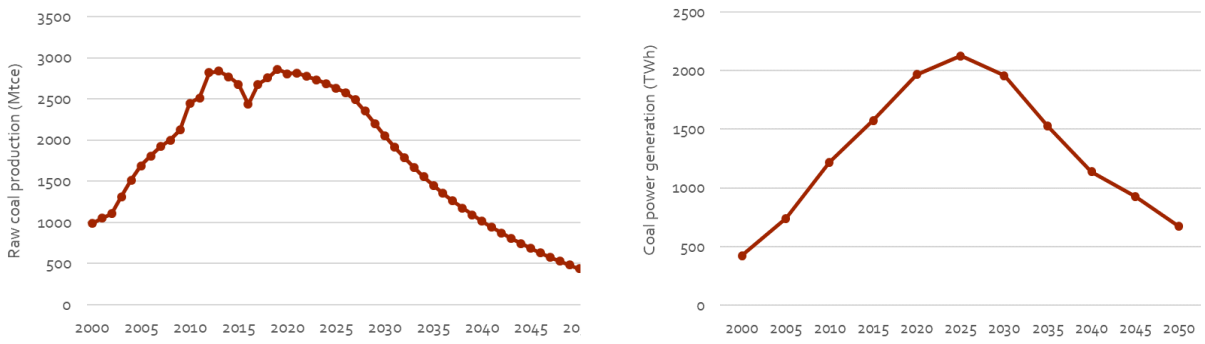
CREO's stated policies scenario further projects that:

- National raw coal production will continue to decline. Coal production will fall to 2,056 Mtce in 2030, or 23.2% below the 2015 level, and to just 438 Mtce in 2050, 83.6% lower than in 2015.

- Coal power generation in the Three North region will peak at around 2,025 (2,125 TWh); in 2035, it will fall below the 2015 level (1,526 TWh); by 2050, it will drop to the minimum (672 TWh). At this time, only in Liaoning will coal power generation remain higher than in 2015.

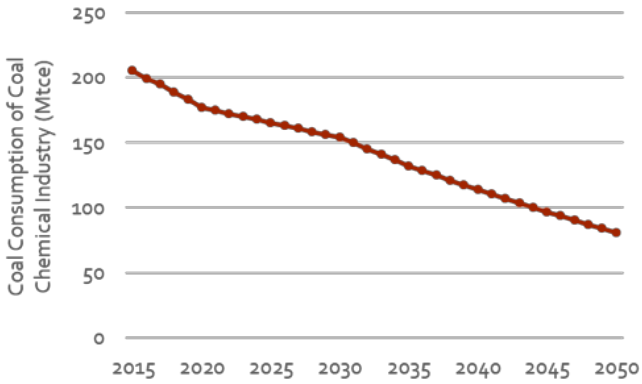
- Coal consumption for the national coal chemical industry will also continue to decline. The coal consumption of the coal-to-gas industry will continue to rise, and after 2030, the proportion of coal consumption in the coal chemical industry will remain stable at around 65%. The total coal consumption in the coal chemical industry is expected to decrease to 154 Mtce by 2030, which is 30.2% lower than in 2015, and to 81 Mtce in 2050, 61.2% lower than in 2015.

2000-2050 national raw coal production (left); 2000-2050 coal power generation in the Three Norths (right)



Source: (left) 2000-2018 data from NBS, accessed in April 2019; 2019-2050 forecast data from CNREC, December 2018. (right) 2000-2015 data from NBS, December 2017; 2020-2050 forecast data from CNREC, December 2018

2015-2050 national coal consumption in coal chemical industry



Source: CNREC, December 2018

3.2 Coal water consumption should rise before falling after 2030

Based on CREO forecasts for the coal industry, and assumptions on coal industry water consumption drawn from Provincial Water Resources Department, Provincial Quality Supervision Bureau, Ministry of Water Resources of the PRC, National Bureau of Statistics of China, Ministry of Industry and Information Technology of China and National Development and Reform Commission, we estimate that from 2015 to 2030 the water consumption in the coal power industry will continue to increase, and as a result the water consumption of the entire coal industry will also increase.[24] During 2030 to 2050, the water consumption in the coal industry will decline rapidly with the shrinkage of the coal power industry. By 2050, total water consumption will fall to less than half of 2015. Therefore, coal industry may not have a significant negative impact on grassland water, animal husbandry and carbon sequestration capacity.

2015-2050 estimate of water consumption of the coal industry in the Three Norths

Unit: million m³	2015	2030	2050
Coal mining and preparation	1,042	800	171
Coal power	3585	4,740	1,888
Coal chemical	559	421	217
Total coal industry	5,185	5,961	2,275

Source: GIZ, December 2018

3.3 Conclusion of section

From 2019 to 2050, water consumption in China's coal industry is expected to increase and then decrease rapidly, which is mainly affected by changes in water consumption in the coal power sector. Based on the projection of the Stated Policies scenario in China Renewable Energy Outlook 2018, coal power generation in the Three North will reach its peak around 2025. Water consumption in coal mining and coal chemical industry both will continue to decline. As for the whole country, raw coal production increased slightly and will decrease after 2019, while coal consumption in the coal chemical industry will continue to decrease. Share of renewable energy in primary energy consumption will increase to 31% and coal's share in primary energy will fall to 14.5% in 2050.

4. Conclusion: The impact of the coal industry on grasslands in the Three Norths should remain small

4.1 Grassland health in the Three Norths shows a positive trend

As the above discussion has shown, this study has found that the coal industry overall, and coal industry water use in particular, has not led to a decline in the Three Norths' grassland biomass or NPP. On the contrary, the region's grasslands have seen rising biomass and NPP over the period studied. A brief spatial analysis suggests that the improvement can be explained mainly by increased precipitation in many areas of the Three Norths during this period. Most grassland in the Three Norths is natural and does not require irrigation, limiting the impact of coal industry water withdrawals; coal industry water withdrawals account for a small share of total water use in the region.

Analysis of specific mining areas by CAS also suggests that policies aimed at limiting the impact of the coal industry on grasslands have helped. Specifically, government policies require that coal development take place simultaneously with efforts to restore grassland and other natural landscapes. The cases discussed in this section show that restoration of grassland have taken place in some areas with former or current mining industry activity. Further study of this topic could combine remote sensing with site visits to develop a more comprehensive inventory of grassland health in the vicinity of coal mining and coal plant operations.

4.2 Future water use for coal may decline

There exists considerable uncertainty about the future of coal and its impact on water and carbon sequestration by grasslands in the Three Norths. China is a middle income country experiencing rapid economic development and high electricity demand growth. Many areas of the Three Norths could develop more quickly than the national average, and energy extraction for export to other areas of China remains an economic pillar of the region. At the same time, China is a signatory to the Paris climate accords, which set the objective of limiting global climate change to well below 2 degrees C. The International Panel on Climate Change (IPCC) has estimated that this will require an early and rapid transition away from fossil fuels in all region, including in Asia, which consumes most of the world's coal currently.[25]

The Stated Policies projection of the China National Renewable Energy Centre projects that China coal industry water consumption in the region will increase moderately through 2030, even as China accelerates its transition to clean energy. Following 2030, CNREC's scenario suggests a rapid decline in coal power, mining and coal-chemicals industries in the region, leading water consumption by these sectors to decline steadily. According to this projection, water consumption by the industry would fall by half between 2030 and 2050. Of course, this projection depends crucially on whether China accelerates its energy transition in line with climate targets.

4.3 Need for further research

Overall, there are many ways in which the coal industry affects water, grasslands, and the carbon balance in the Three Norths. This study has approached the issue from the highest level, determining the overall trends in regional grassland health, coal plant water consumption as a share of water use in the region and within each watershed, and the potential relationships between these factors. Overall, we find that the regional grassland health and carbon sequestration are mainly improving, and that this can be attributed mainly to precipitation changes; given low water withdrawals directly for coal power, we see no overall impact from this factor on regional water use and grassland

carbon. This finding contrasts with earlier work on this subject, which has emphasized the potential risks of locating a large fraction of China's coal industry in a region with high water stress. The recovery of China's grasslands should exert a positive, albeit small, impact on the carbon balance, even as China's greenhouse gas emissions continue to contribute a large fraction of global emissions.

Direct water withdrawals, and correlation between water consumption and grassland health, represent an initial approach to the question of how the coal industry affects regional ecology. In the future, remote sensing studies may enable a wider evaluation of topics this paper has not addressed. This could include the effect of coal power and coal mining on groundwater depletion, surface water diversions, groundwater contamination, and the relationship with nearby agriculture or ecology. In particular, coal ash disposal, wastewater disposal, and groundwater depletion represent topics of future research.

Coal ash disposal has recently become an important topic of research worldwide after the failure of several coal ash ponds in the U.S. and elsewhere. In the U.S., a developed nation with a long record of environmental laws and policies related to water and toxic waste, policymakers only in 2018 began requiring coal plant owners to report groundwater data associated with disposal of coal ash. Of the over 500 sites that have posted groundwater data, 91% had groundwater contamination at levels exceeding U.S. federal clean water standards. Hundreds of sites associated with closed coal plants were not reported.[26]

Coal-related waste disposal has also been an issue in China, where investigations of coal-to-chemicals sites in Inner Mongolia showed signs of serious groundwater contamination near coal-to-chemicals wastewater disposal sites as well as failure to comply with relevant regulations—allegations that local government officials subsequently followed up on.[27] As noted previously, China has adopted policies that favor rapid cleanup and restoration of coal plant sites in these areas.

Since the economics of coal power typically favor coal plants located near mines, the impact of coal power is inexorably linked to coal mining. Recent research has shown that coal mining activities in Shaanxi province, within the Three Norths region, has been the main contributor to drawing down groundwater in the study area near Yulin.[28] Specifically, the study found that mining water drainage has a strong impact on the quantity of groundwater resources, depleting resources in semi-arid regions that could not be replaced by precipitation, and that the lowering of the water table in the area has also affected surface water flows in the region, while also polluting and acidifying remaining groundwater resources.

4.4 Concluding thoughts

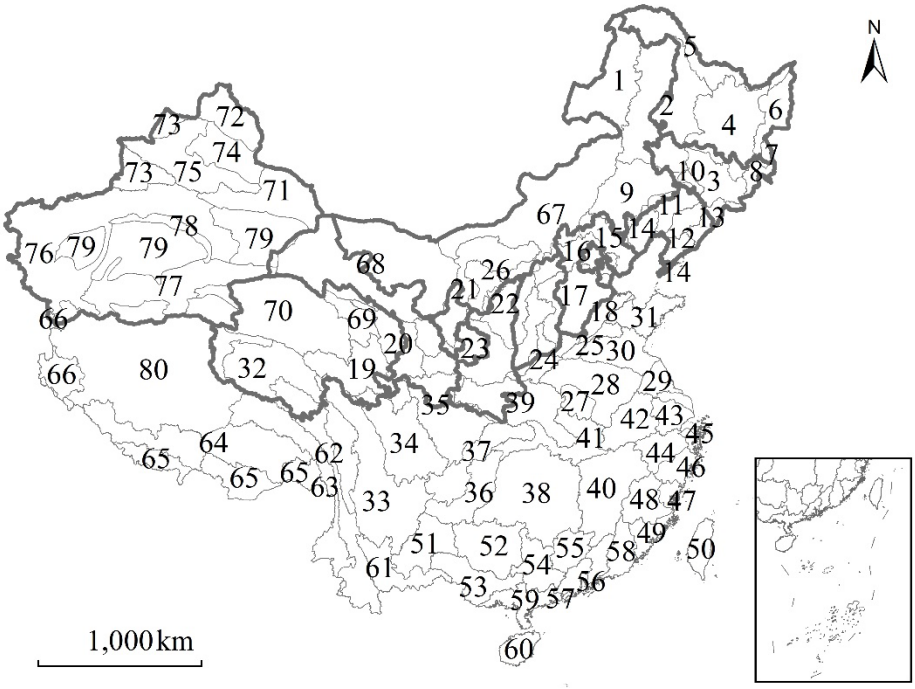
This study represents a broad study of the overall spatial relationship between the coal industry, water stress, and grassland productivity/carbon sequestration across China's Three Norths region. This correlational overview suggests that coal plant water withdrawals do not appear linked to overall grassland carbon sequestration in the Three Norths. Instead, other factors appear mainly responsible for improved grassland NPP, even during a period when coal power production has surged in China. However, this analysis represents a first look at this relationship, and that deeper spatial analysis and case studies are likely to reveal patterns at the local level.

Based on the Stated Policies projection of CREO 2018—which anticipates China's coal consumption and power production will peak and then decline rapidly to 2050—and a crude projection of coal industry water consumption, we estimate that the coal industry's water consumption will rise to 2025 and then decline steeply. However, we note that annual water consumption tells only part of the story, since the coal industry can affect water supplies long after mines and plants have closed—as shown by studies of groundwater depletion and groundwater contamination at the local level. We believe these issues merit further investigation both at the local and national level, and the results of such investigation could assist national planners in determining future ecological red lines across the Three Norths.

Appendix Catchments in China and coal power capacity and NPP by catchments

This study divides China into 80 catchments according to water resources regionalization in China.

Catchments in China



Source: CAS, December 2018

Catchments in China

ID	Catchment Name	ID	Catchment Name	ID	Catchment Name	ID	Catchment Name
1	Argun River	21	Lanzhou to Hekou	41	Yichang to Hukou	61	Red River
2	Nen River	22	Hekou to Longmen	42	Mainstream after Hukou	62	Lancang River
3	Second Songhua River	23	Longmen to Sanmenxia	43	Lake Tai River System	63	Nujiang River (also called Salween or Thanlwin River) and Irrawaddy River (also called Ayeyarwady River)
4	Songhua River under Sanchakou (also called First Songhua River)	24	Sanmenxia to Huayuankou	44	Qiantang River	64	Yarlung Tsangpo (also called Yarlung Zangbo or Yalu Zangbu)
5	Amur River Main Stem	25	Below Huayuankou	45	Rivers in Easten Zhejiang	65	Rivers in Southern Tibet
6	Ussuri River	26	Inflow Zone	46	Rivers in Southern Zhejiang	66	Rivers in Western Tibet
7	Suifen River (also called Razdolnaya River)	27	Huai River Upstream (before Wangjiaba)	47	Rivers in Eastern Fujian	67	Inland Rives in Inner Mongolian Plateau
8	Tumen River	28	Huai River Midstream (Wangjiaba to Hongze Lake Exit)	48	Min River	68	Inland Rivers in Hexi Corridor
9	Xiliao River	29	Huai River Downstream (after Hongze Lake Exit)	49	Rivers in Southern Fujian	69	Qinghai Lake River System
10	Dongliao River	30	Yihe River, Shu River and Si River	50	Rivers in Taiwan, Penghu, Kinmen, and Matsu Islands	70	Qaidam Basin (also called Tsaidam)
11	Liao River Main Stream	31	Rivers along the sea in Shandong Peninsula	51	Nanpan River and Beipan River	71	Small Rivers in Turpan Depression and Hami Depression (also called Kumul Depression)
12	Huntai River	32	Jinsha River (before Shigu)	52	Hongliujiang River	72	Rivers in Southern Altai Mountains
13	Yalu River	33	Jinsha River (after Shigu)	53	Yu River	73	Inland Rivers Zone in Central and Western Asia
14	Rivers along the Yellow Sea and the Bohai Sea in Northeast China	34	Min River and Tuo River	54	Xi River	74	Gurbantünggüt Desert
15	Luan River and Rivers along the sea in Easten Hebei	35	Jialing River	55	Bei River	75	Rivers in Northern Tian Shan (also called Tengri Tagh)
16	Hai River (North)	36	Wu River	56	Dong River	76	Source of Tarim River
17	Hai River (South)	37	Yibin to Yichang	57	Pearl River Delta	77	Small Rivers in Northern Kunlun Mountains)
18	Tuhai River and Majia River	38	Dongting Lake River System	58	Han River and Rivers in Eastern Guangdong	78	Tarim River Mainstream
19	Longyangxia Dam Upstream	39	Han River	59	Rivers along the sea in Western Guangdong and Southern Guangxi	79	Tarim Basin Desert
20	Longyangxia Dam to Lanzhou	40	Poyang Lake River System	60	Rivers in Hainan and South China Sea Islands	80	Inland Rivers in Qiangtang Plateau

Notice: Grey areas are related to the Three Norths.

NPP and coal power installed capacity in each catchment in the Three Norths region

Catchment ID	NPP (Tg.C)	Coal power installed capacity (MW)	Share of NPP by catchment	Share of Coal power installed capacity by catchment
1	19.29229	6800	7.15%	2.04%
2	17.23951	13520	6.39%	4.05%
3	0.707032	6131	0.26%	1.83%
4	2.333232	9770	0.87%	2.92%
5	3.262647	0	1.21%	0.00%
6	0.977727	2890	0.36%	0.86%
7	0.170744	0	0.06%	0.00%
8	0.220912	1060	0.08%	0.32%
9	14.49499	7270	5.37%	2.18%
10	0.052838	660	0.02%	0.20%
11	1.187651	7280	0.44%	2.18%
12	0.107072	5075	0.04%	1.52%
13	0.254052	2675	0.09%	0.80%
14	2.986602	10380	1.11%	3.11%
15	4.483794	9606	1.66%	2.87%
16	4.491327	29040	1.67%	8.69%
17	7.461227	39649	2.77%	11.87%
19	14.26559	0	5.29%	0.00%
20	14.52514	5675	5.39%	1.70%
21	10.49283	48620	3.89%	14.55%
22	10.24772	28620	3.80%	8.57%
23	21.46753	41950	7.96%	12.56%
24	1.081915	3900	0.40%	1.17%
26	3.036591	660	1.13%	0.20%
32	3.734279	0	1.38%	0.00%
33	0.719241	0	0.27%	0.00%
34	1.710231	0	0.63%	0.00%
35	11.60169	660	4.30%	0.20%
37	0.000526	0	0.00%	0.00%
39	12.67077	0	4.70%	0.00%
62	2.239323	0	0.83%	0.00%
63	0.001174	0	0.00%	0.00%
67	33.88923	4530	12.57%	1.36%
68	5.669133	5930	2.10%	1.77%
69	4.051656	0	1.50%	0.00%
70	2.100112	0	0.78%	0.00%
71	1.484295	5950	0.55%	1.78%
72	6.365252	0	2.36%	0.00%
73	10.47133	760	3.88%	0.23%
74	0.422199	5550	0.16%	1.66%
75	8.114918	24605	3.01%	7.36%
76	8.044711	2790	2.98%	0.84%
77	0.670412	0	0.25%	0.00%
78	0.290763	800	0.11%	0.24%
79	0.01749	1320	0.01%	0.40%
80	0.28997	0	0.11%	0.00%

Reference

1 For example, 80% of land destroyed annually by mining activities was from coal mining, see "Land reclamation unleashes new life," Ministry of Agriculture, 25 September 2013, accessed at http://english.agri.gov.cn/news/dqnf/201309/t20130925_20298.htm; For information on metals pollution from coal plants and impacts on agriculture, see Ran Li et al., "Mercury pollution in vegetables, grains and soils from areas surrounding coal-fired power plants," Nature, 9 May 2017, accessed at https://www.nature.com/articles/srep46545. For a vivid example of how herders and other agricultural workers were affected by one coal plant, see "Thirsty Coal 2: Shenhua's Water Grab," Greenpeace East Asia, 2013, accessed at http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2013/Thirsty%20Coal%202.pdf.

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