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Carbon Footprint of the Agricultural Sector in Qinghai Province, China

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Abstract: The agricultural sector has become an important emitter of greenhouse gases in China. The CO_2 emissions in the western undeveloped region have attracted less attention than those in the eastern developed region in China. In this paper, the change in carbon footprint (CF) caused by agrochemical and agricultural energy inputs, the contributions of various inputs to the total carbon footprint (TCF), and the different changing trends between carbon intensity in output value (CV) and carbon intensity in area (CA) in Qinghai province were studied based on the data for agrochemical and energy inputs over 1995–2016. The change in TCF had a roughly stable period over 1995–1999, a slowly decreasing period over 2000–2007, and a rapidly increasing period over 2008–2016, which generally synchronize with the periods of before the Grain for Green Policy (GFGP), during the GFGP, and after the GFGP, respectively. The chemical nitrogen fertilizer and energy inputs were the principal factors influencing the TCF. The N fertilizer was the highest contributor to the TCF and contributed more to the relatively lower TCF during the GFGP in the study area. The relative CF caused by plastic film and diesel input in the study area increased faster than that in the whole country. The CV declined, with a mean of 0.022 kg carbon equivalent (CE)/Chinese Yuan (CNY), which was 55.59% of the mean CV in China over 1995–2016; inversely, the CA obviously rose after 2007, with a mean of 5.11 kg CE/ha, which was only 1.94% of the mean CA in China from 1995 to 2016. Compared with the whole country, Qinghai province generally had a higher rate of increase of carbon efficiency accompanied by a higher rate of increase of CA. The improvements of local agricultural activities should aim to keep a balance between higher carbon efficiency and lower CA in the study area.

Keywords: carbon emissions; emission coefficient; agricultural land; agricultural inputs; agricultural policies; Qinghai province

1. Introduction

CO_2 emissions have kept increasing due to large-scale use of fossil fuels and have attracted global attention [1]; and recent human-induced emissions of greenhouse gases are reaching the highest levels in history [2]. Increasing human-induced CO_2 emissions may affect climate change and limit the sustainable development of human society and economy [3]. In order to study the trend and affecting factors of CO_2 emissions in different production sectors and to promote the green economic development, many researchers have used the evaluation methods of carbon footprint (CF) in different research fields [4–6].

China is a country with a long history of agricultural civilization. Because of the population increase, economic development, improvement of living standards, and limitation of agricultural land resources, the modern agricultural production mainly depends on agrochemicals and fossil fuels both in the economically developed and underdeveloped regions in China [7]. In order to combat serious ecological degradation in its economically underdeveloped regions, China has launched a few key ecological and agricultural policies or projects. Large-scale policies or projects have strongly affected the agrochemical and energy inputs. Previous studies have paid more attention to human-induced CO_2 emissions for agricultural production, their potential risks to the environment, and ways of reducing agricultural carbon emission by using CF evaluation in economically developed regions [8–11]; yet, relatively few studies have focused on the change in CF for agricultural production in its ecologically vulnerable and economically underdeveloped regions, which have also been strongly affected by the rapid development of the economy in China.

Human-induced CO_2 emissions for agricultural production and their potential risks to the environment are closely related to the area and location of agricultural land and the agrochemical and energy inputs. As a type of highly intensive agricultural land, cropland sometimes decreases due to the change of cropland into construction land for regional economic development and the change of low quality cropland to forest or grassland for ecological security, but sometimes it increases because of the change of grassland or forest to cropland for food security in the ecologically vulnerable regions in China [12–14]. The Chinese government always tries to keep a balance between decreasing the ecological degradation and increasing the agricultural efficiency. In order to reduce the adverse effects of ecological and agricultural policies on agricultural production and to support and benefit farmers, the Chinese government has launched some preferential agricultural policies after the Grain for Green Policy (GFGP) [15]. For example, focusing on "agriculture, rural areas, and farmers", 12 consecutive "Central First Documents" were released from 2004 to 2015 [16]. The implementation of the mentioned agricultural policies has effectively changed the agricultural land use structure and input structure in China, especially in the GFGP implementation area since the early 1990s. Thus, it is necessary to study the total carbon footprint (TCF) trend and its potential risks to the environment in its ecologically vulnerable and economically underdeveloped regions.

The above-mentioned ecologically vulnerable and economically underdeveloped regions are mainly located in western China, with physical geographical characteristics of the obvious change in altitude, more mountain and plateau landscapes, great daily or seasonal range of temperature, and frequently occurring droughts, floods, and strong storms [17]. The GFGP has mainly launched in western China, which mainly covers five topographic regions. Some studies have paid attention to the CO_2 emissions for agricultural production and their potential risks to the environment in northwest China [18], Loess Plateau [19], Sichuan Basin [20], and Yunnan–Guizhou Plateau [21]. In fact, the CO_2 emissions for agricultural production and their potential risks to the environment on the fragile Tibetan Plateau should be paid more attention, because the Tibetan Plateau is always regarded as a driver and amplifier of the global climate change and the birthplace of China's major rivers.

Taking Qinghai province on the Tibetan Plateau as a study area, and using carbon footprint analysis as the evaluation method, the authors have the following study goals: (1) To estimate the changing trend in TCF of the agricultural sector in Qinghai province associated with the GFGP implementation periods; (2) to recognize the main factors affecting CO_2 emissions associated with the structure of agricultural inputs; and (3) to assess the different changing trends between carbon intensity in output value and carbon intensity in area in order to hold a balance between higher carbon efficiency and lower carbon intensity in area (CA) in the study area.

2. Data Sources and Research Methodology

2.1. Study Area

Located in the northeast region of the Tibetan Plateau, Qinghai province has a geographical position of north latitude 31°39′–39°19′, east longitude 89°35′–103°04′. It covers an area of 7.18×10^5 km^2, ranking fourth in China (Figure 1). It has an annual average temperature between −5.6 and 8.6 °C and an annual precipitation ranging from 17.6 to 764.4 mm. The average elevation is over

3000 m, with a peak of 6860 m and a low point of 1650 m. As the birthplace of China's major rivers, it has a terrain higher in the southern and western region and lower in the eastern and middle region. Its sunshine is long and the solar radiation is strong. The annual sunshine reaches 2300–3600 h and the total radiation quantity in the province is 585.20–739.86 KJ cm^{-2}, second only to the Tibet autonomous region in China [22].

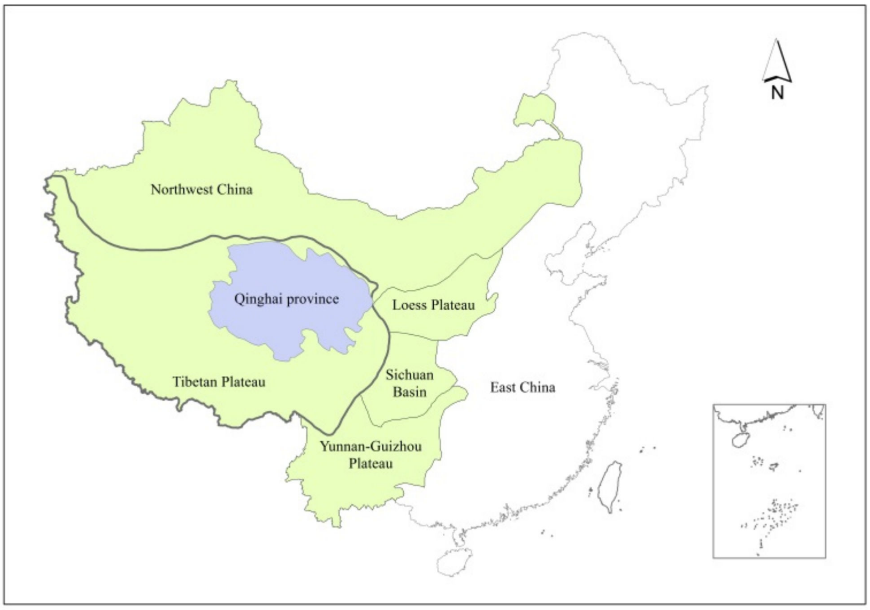

Figure 1. Division of western China and location of Qinghai province, China (The division of western China was based on Wang and Shen [17]).

Agricultural land use types in Qinghai province mainly included cropland, orchard, grassland, and forest land, with proportions of 0.76%, 0.01%, 56.25%, and 3.69%, respectively in 2006 [22]. Agricultural output value increased over 1995–2016, especially after 2007 (Figure 2). The output value from planting and stock raising contributed about 96% of the total agricultural output value. The output value from planting was basically equivalent to that from stock raising, although the latter was slightly higher than the former after the GFGP.

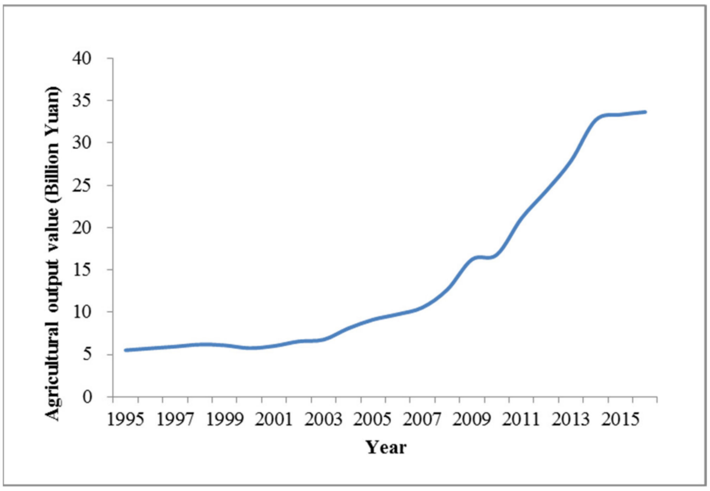

Figure 2. Agricultural output value in Qinghai province over 1995–2016.

2.2. Data Sources

The data for cropland, orchard, grassland, and forest land areas were based on the published data [22,23] and the Third Pole Environment Database [24] .The input data for chemical fertilizers, pesticides, and plastic film were obtained from the National Data for the period 1995–2016 [25]. The agricultural output value for the initial year of the study period and the annual increasing index of agricultural output value for Qinghai province over 1995–2016 were also obtained from the National Data for the period 1995–2016 [25]. The consumption data for raw coal, gasoline, diesel, and electricity were obtained from the energy consumption in the agricultural sector in Qinghai province from 1995 to 2016 [26].

2.3. Research Methodology

By considering each section of emissions of greenhouse gases in carbon equivalent (CE), the TCF in the agricultural sector was estimated over 1995–2016, which was caused by 10 main inputs of chemical fertilizers, pesticides, plastic film, raw coal, gasoline, diesel, and electricity. The TCF for agricultural production mainly consists of two parts, i.e., (1) indirect emissions of greenhouse gases from the manufacture of chemical fertilizers, pesticides, and plastic film and (2) direct emissions of greenhouse gases from the raw coal, gasoline, diesel, and electricity used by agricultural activities. Based on the published data [27], the annual emission coefficient for electricity use was estimated, which ranged from 0.23 to 0.18 kg C/kWh over 1995–2016. The coefficient for N_2O emissions from chemical fertilizer-N application in Qinghai province was based on the regional mean value of 0.0056 kg N_2O–N/kg N fertilizer in northwestern China [28], which was lower than the mean of the whole country [29]. The direct N_2O emissions from chemical fertilizer-N application in agricultural lands should be taken into account, because it was one of the major contributors to the TCF [8].

The CF of individual emission source input for agricultural production was estimated based on Equation (1):

$$CF = ES \times EC, \tag{1}$$

where *CF* is the carbon footprint in carbon equivalent (CE) for CO_2 emissions caused by individual emission source input; *ES* is the amount of individual emission source input; and *EC* is the individual emission coefficient. Table 1 lists the individual emission source and coefficient in the agricultural sector in Qinghai province.

Table 1. Main emission sources and emission coefficients in the agricultural sector in Qinghai province.

	Emission Source	Emission Coefficient (kg C/kg)	Reference
Agrochemicals	Nitrogen	1.74	[30]
	Phosphorus	0.20	[10]
	Potassium	0.15	[10]
	Pesticides	6.00	[10]
	Plastic film	2.58	[9]
Energy	Raw coal	0.52	[29,31]
	Gasoline	0.80	[29,31]
	Diesel	0.84	[29,31]

The CF for N_2O emissions caused by chemical N fertilizer use was estimated based on Equation (2):

$$CF = 127.21 \times 0.0056N, \tag{2}$$

where *CF* is the carbon footprint in carbon equivalent for N_2O emissions caused by N fertilizer use; *N* is the amount of N fertilizer used; 0.0056 is the emission coefficient for N_2O emissions caused by N fertilizer application in the study area; and 127.21 is the conversion coefficient [8,32].

The TCF caused by agrochemical and energy inputs was calculated based on Equation (3):

$$TCF = \sum_{i=1}^{10} ES_i EC_i, \quad (3)$$

where TCF is the total carbon footprint, ES_i is the input amount of the emission source i; EC_i is the emission coefficient of emission source i; and i means the main type of emission source, which ranges between 1 and 10.

Two types of carbon intensities were selected to describe the economic benefits and related environmental issues caused by CO_2 emissions for agricultural production [10]. Carbon intensity in output value (CV) means the total carbon footprint per unit of agricultural output value. Carbon efficiency can be used to directly reflect the benefit of agricultural production at the expense of agricultural CO_2 emissions, which is the reciprocal of CV. Carbon intensity in area (CA) means the total carbon footprint per unit of agricultural land area, which can be used to reflect the potential environmental problems.

In order to reflect the relative carbon efficiency and potential environmental problems in Qinghai province, comparative analysis of the changing trends of TCF, CV, and CA was used between the study area and the whole country.

3. Results and Analysis

3.1. Change in TCF for Agricultural Production

The TCF induced by 10 main types of agrochemical and energy inputs rose from 194.30 to 309.89 Kt CE (1 Kt = 10^3 t) over 1995–2016. It had a mean value of 222.22 Kt CE and a yearly rate of increase of 2.83% over the study period (Figure 3 and Table 2). Three time periods could be found for the TCF changing trend over 1995–2016, i.e., a five-year period over 1995–1999, an eight-year period over 2000–2007, and a nine-year period over 2008–2016 (Figure 3). The TCF was roughly stable over 1995–1999, with a lower yearly rate of increase of 1.57%; slowly declined over 2000–2007, with a yearly decreasing rate of 1.02%; and rapidly rose over 2008–2016, with a higher yearly increasing rate of 4.85%. The mean value of TCF decreased from the first period to the second period; yet, it increased from the second period to the third period. Distinct change in TCF occurred from 2007 to 2008. Indicated by Figure 3, the relative TCF was lower during the GFGP in the study area, which was obviously different from that in the whole country [3].

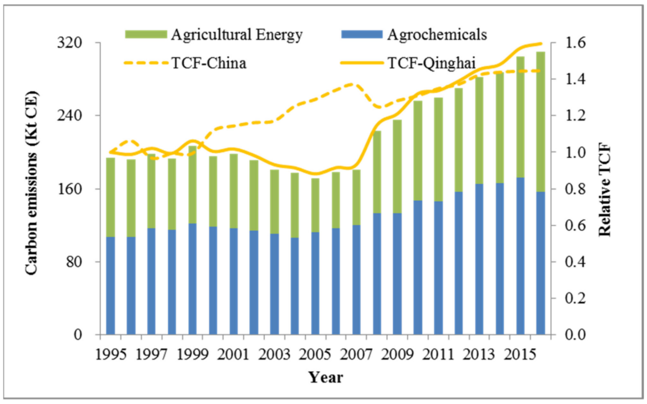

Figure 3. Changing trends of carbon footprints induce by agrochemical and agricultural energy inputs in Qinghai province over 1995–2016. TCF—total carbon footprint.

Table 2. Mean TCF and mean agricultural output values for four periods.

Year	Mean TCF (Kt CE)	TCF Growth Rate (%)	Mean AV (BCNY *)	AV Growth Rate (%)	Relative Contribution by N (%)	Relative Contribution by Energy (%)
1995–1999	196.92	1.57	5.89	2.61	49.57	42.36
2000–2007	184.19	−1.02	7.82	11.94	51.89	37.78
2008–2016	270.08	4.85	24.30	20.70	44.98	43.16
1995–2016	222.22	2.83	14.12	24.32	48.54	41.02

* Note: 1 BCNY = 10^9 CNY (Chinese Yuan); 1 Kt = 10^3 t.

3.2. Relative Contributions of Agricultural Inputs to the TCF

The relative contributions of carbon footprints induced by 10 main agricultural inputs to the TCF for four periods are displayed in Figure 4. Based on the values of relative contributions for various agricultural inputs from 1995 to 2016, the contributors could be divided into three groups, i.e., higher contributors, including nitrogen (48.54%), electricity (13.65%), and diesel (12.36%); moderate contributors, including raw coal (9.23%), gasoline (5.78%) and pesticides (4.99%); and lower contributors, including plastic film (2.56%), phosphorus (2.09%), and potassium (0.80%). The relative contributions indicated that 92.46% of the TCF was contributed by chemical fertilizers and energy consumption; while only 7.54% of the total CF was contributed by pesticides and plastic film use (Figure 4). The CF caused by nitrogen input induced N_2O was even greater than that caused by electricity use. The CF caused by energy consumption was 41.02% of the TCF. Particularly, the relative contribution of CF caused by electricity use roughly decreased from 1995 to 2011; however, it rapidly increased after 2011.

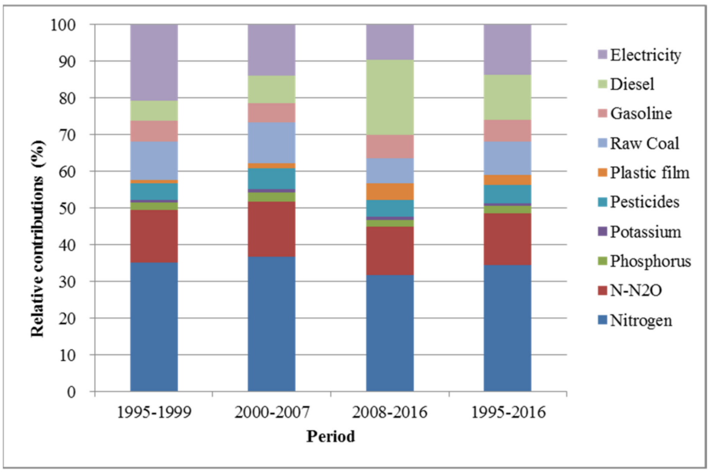

Figure 4. Relative carbon footprint (CF) contributions of 10 emission sources to the TCF.

The CF caused by plastic film was only 2.56% of the TCF; yet, it had a higher rate of increase than those caused by other agrochemical inputs over 1995–2016. The relative CF caused by plastic film in the study area increased even faster than that in China. The CF caused by diesel was 12.36% of the TCF, lower than that by electricity; yet, it had a higher rate of increase than those caused by other agricultural energy inputs over 1995–2016. The relative CF caused by diesel in the study area also increased faster than that in China (Figure 5).

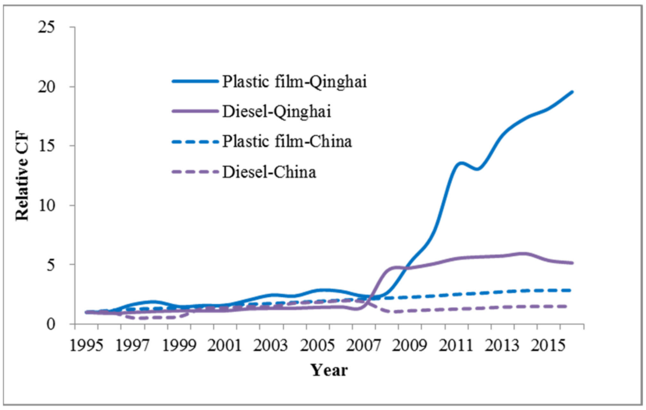

Figure 5. Changes in the relative CFs of plastic film and diesel in Qinghai province and China.

The relative CF contributions of 10 emission sources to the TCF for four time periods are shown in Table 2 and Figure 4. The changing trend of TCF was mainly controlled by that of carbon footprints induced by N fertilizer and energy inputs. The relative mean CF contribution of N fertilizer to the TCF increased from 49.57% during the period 1995–1999 to 51.89% during the period 2000–2007, then dropped to 44.98% during the period 2008–2016 (Table 2). The changing trend for relative mean CF contribution of agricultural energy to TCF was contrary to that of N fertilizer to the TCF. Therefore, higher proportion of N fertilizer input over 2000–2007 during GFGP and higher proportion of agricultural energy consumption over 2008–2016 after GFGP could be found in the study area. Compared with the whole country [3], the study area had a lower proportion of N fertilizer input and a higher proportion of agricultural energy consumption.

3.3. Changing Trends of Carbon Intensity in Output Value and Carbon Intensity in Area

The agricultural output value rapidly increased from 2007 to 2016, with an annual rate of increase of 24.32% over 1995–2016, which was about three times that for China. The CV declined from 0.035 to 0.009 kg CE/Chinese Yuan (CNY) over 1995–2016 (Figure 6). The changing trend of CV indicated that the carbon efficiency was improved, partly because both agricultural land use structure and agricultural input structure were gradually optimized according to the market demands. The average CV was 0.022 kg CE/CNY, which was only 55.59% of the average CV in China over 1995–2016 [3,33]. Based on the ratio of CV in the studied years to that in the initial year of the study period, the relative CV in Qinghai province was higher than that in China over 1995–2002; however, it was lower than that in China over 2003–2016 (Figure 7). The ratio of CV in Qinghai province to that in China was roughly decreased from 0.65 in 1995 to 0.33 in 2016 (Figure 8). Thus, the CV in Qinghai province was lower than that in China; however, the rate of increase of carbon efficiency in Qinghai province was higher than that in China.

A roughly increasing trend of CA could be found over 1995–2016; however, the CA was lower over 2000–2007 during the GFGP (Figure 6). The mean CA was 5.11 kg CE/ha, which was only 1.94% of the mean CA in China over 1995–2016. Based on the ratio of CA in the studied years to that in the initial year of the study period, the relative CA in Qinghai province was generally lower than that in China over 1995–2012; however, it was higher than that in China over 2014–2016 (Figure 7). The ratio of CA in Qinghai province to that in China was roughly decreased from 0.021 in 1995 to 0.014 in 2007; however, it was roughly increased from 0.014 in 2007 to 0.024 in 2016 (Figure 8). Thus, the CA in Qinghai province was much lower than that in China; however, the rate of increase of CA in Qinghai province accelerated after 2007, and became higher than that in China after 2013. It is clear that the increase in carbon efficiency was accompanied by an increase in CA, especially after 2007 in the study area.

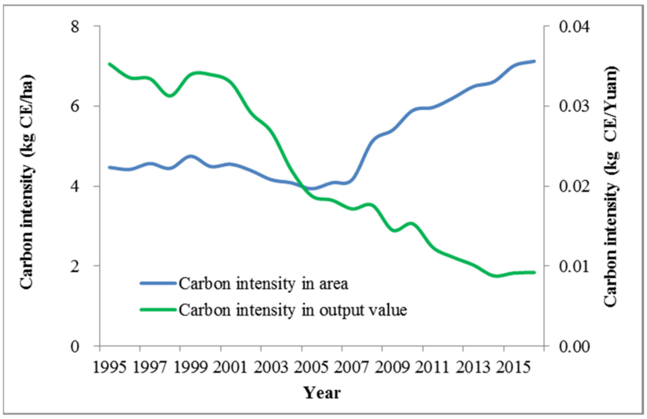

Figure 6. Change in carbon intensity in Qinghai province over 1995–2016.

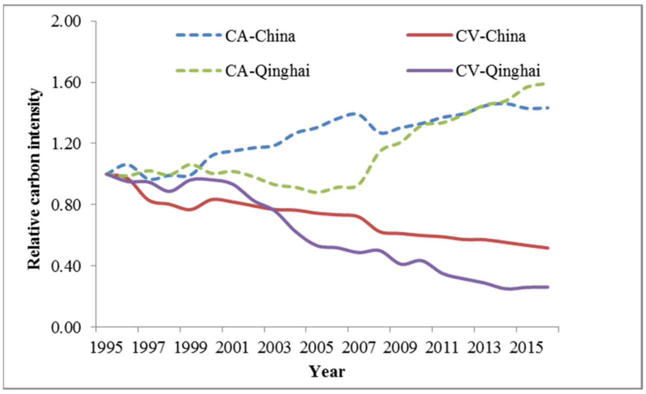

Figure 7. Change in relative carbon intensity in Qinghai province and China over 1995–2016.

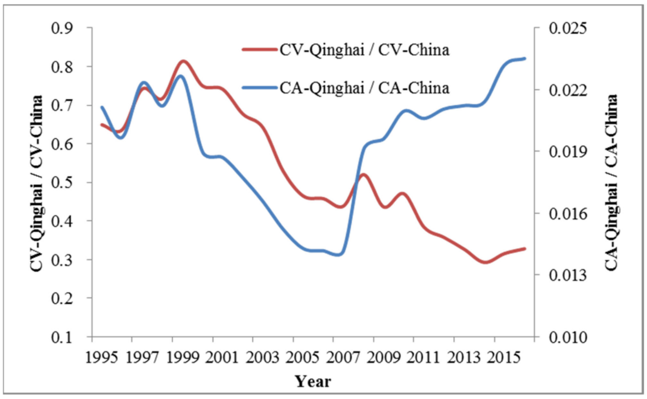

Figure 8. Change in ratio of carbon intensity in Qinghai province to that in China over 1995–2016.

4. Discussion

4.1. Related Agricultural Policies Affect the TCF

The changing trend of TCF was affected by the related national and local agricultural policies. The TCF had experienced roughly stable, slowly decreasing, and rapidly increasing periods, which were related to the periods 1995–1999 before the GFGP, 2000–2007 during the GFGP, and 2008–2016 after the GFGP. From 1995 to 1999, the TCF was roughly stable, because the food security should have been guaranteed by intensifying agricultural land use or expanding cropland area [25,26]. From 2000 to 2005, the TCF decreased, because the ecological security should have been guaranteed mainly by reducing cropland at high risk of degradation, and the agricultural inputs were relatively lower over 2000–2005 of the initial implementation period of GFGP in the study area, which was obviously different from other GFGP implementation areas in western China [34].

The TCF slightly increased between 2006 and 2007, probably because some contingency policies were implemented to keep the balance between the food security and ecological security in the late implementation period of the GFGP period [35]. In order to control the increasing TCF and to maintain the agricultural production, China adopted many specific low-carbon agricultural techniques [36]; however, the overall agricultural energy efficiency was low, especially in undeveloped western China [37]. In addition, the environmental pollution induced by higher agrochemical inputs has not attracted wide public attention because this type of concealed and dispersed pollution is difficult to detect [38]. The TCF in the study area rapidly increased between 2008 and 2016, and the CF proportion by energy input during that period was relatively higher. This was because that the cropland and orchard area had slightly increased and all agricultural inputs had generally increased after the implementation period of GFGP. The changes in agricultural policies and associated agricultural land use structure and input structure strongly affected the changing trend of TCF for agricultural production in the study area, which were also evident in China [3], Jordan [39], the Indo-Gangetic Plains [40], and the South American Chaco [41].

As a part of driver and amplifier of the global climate change, Qinghai province should control its relatively lower but increasing TCF. Based on the changing trends for CV and CA in Qinghai province over 1995–2016 (Figure 6), the input structure and intensity of agrochemical and energy during 2005–2007 may be comparatively reasonable to hold a balance between higher carbon efficiency and lower CA in the study area under certain natural and economic conditions. In order to limit the increasing TCF, it is necessary to control the application amount and use efficiency of N fertilizer, diesel, and plastic film.

4.2. Agricultural Carbon Efficiency and the Associated Environmental Problems

The decreasing trend of carbon intensity in output value and increasing trend of agricultural carbon efficiency in Qinghai province were mainly determined by the increasing proportion of the agricultural products with higher economic output value and the change in agricultural input structure over the study period. However, the population growth, increase in food and income demands, implementation of series of ecological and supporting agricultural policies, (especially the GFGP during 2000–2007), and the unique fragile plateau environment not only result in the increasing trend of carbon intensity in area but also cause other associated environmental problems.

The rural population in Qinghai province rose from 3.23 million to 3.96 million between 1995 and 2016, with an annual increment of 37.60 thousand. Meantime, the grain crop production increased from 1.42 million tons to 1.46 million tons over 1995–2016, with an annual increment of 3.52 thousand tons; while the cash crop production increased from 0.55 million tons to 2.00 million tons over the study period, with an annual increment of 77.98 thousand tons. Practically, the cash crop production exceeded the grain crop production in Qinghai province after 2009. Therefore, the increasing agricultural carbon efficiency mainly depended on the increasing cash crop production. Based on National Survey Data, compared with major grain production, vegetable production requires 2.1 times input of chemical fertilizers, 5.5 times input of pesticides, and 61.9 times input of plastic film in China, respectively [42]. Thus, more agrochemical inputs have to be used to increase the production of high-valued cash crops.

Therefore, the N fertilizer application had increased from 64.42 to 80.99 kg/ha between 1995 and 2016, with a mean of 73.54 kg/ha in Qinghai province, which was 33.91% of the mean in the whole country; while the P fertilizer application had increased from 30.51 to 45.02 kg/ha between 1995 and 2016, with a mean of 38.87 kg/ha in Qinghai province, which was 39.91% of the mean in the whole country. Based on the National Data [25], China has exceeded its safe N input limit of 170 kg/ha since 1995, and safe P_2O_5 input limit of 80 kg/ha since 2001 [43,44]. Although the chemical fertilizer applications were under the general safe environmental limits for N and P_2O_5 in Qinghai province, the indisputable fact is that all agrochemical inputs increased after 2007. Thus, the agrochemical input intensity during 2005–2007, which may be comparatively reasonable to hold a balance between higher carbon efficiency and lower CA, and the unique safe environmental limits of agrochemicals and energy on the plateau need further studying.

Currently, it is necessary to efficiently use high-quality agrochemicals and energy, and to develop more biological and eco-friendly agricultural additions on the fragile plateau in order to increase agricultural carbon efficiency and to control the associated environmental problems [45]. In addition, as the birthplace of China's major rivers, Qinghai province should impose heavy environment taxes on agrochemicals and energy and waive value-added taxes on biological and eco-friendly agricultural additions [46], which will be useful for the improvement of the local and downstream environmental conditions. New technologies and methods for carbon capture, storage and rational use (e.g., CO_2 injection enhanced oil recovery), and manufacture of high-quality and low-pollution agrochemicals and energy should be experimentally used to protect the fragile plateau [47–51].

4.3. Uncertainty of Evaluation of the TCF and the Related CV and CA

The TCF caused by 10 main types of agricultural inputs for agricultural production and the related CV and CA in Qinghai province on the Tibetan Plateau over 1995–2016 were evaluated. However, the authors should list some sources of uncertainty for evaluation of the TCF. Due to lack of relevant data, the construction, maintenance, and enhancement of agriculture infrastructure were not regarded as emission sources, which affected the evaluation of annual absolute TCF in the study area. Furthermore, the regional difference of emission coefficients for 10 main types of agrochemicals and agricultural energy also affected the TCF evaluation. Uncertainty of evaluation of CA could be unavoidable, because the 10 main types of agrochemicals and agricultural energy were mainly used in cropland and orchard. Thus, the TCF per unit of agricultural land area could not reflect the detailed CA in cropland, orchard, forest, and grassland. Uncertainty of evaluation of CV could also be unavoidable, because some new agricultural varieties were sometimes used, which affected the index for agricultural output value. However, the mentioned sources of uncertainty could not interfere with the general changing trend of CF caused by each main agricultural input in Qinghai province over 1995–2016. Referring to the study by Li et al. [52], more emission sources and detailed emission coefficients with regional characteristics should be taken into consideration to study the carbon footprint in future works. Located in the eastern agricultural area of Qinghai province, the Hehuang valley should be taken as a key study area to further study the carbon footprint of agricultural sector and its affecting factors. The valley has a land area accounting for about 26.3% of the total area of Qinghai province but a cropland area accounting for 60.8% of the province's total cropland area [53].

5. Conclusions

The socioeconomic development and implementation of a series of ecological and supporting agricultural policies since 1995 affected the changing trends of total carbon footprint, carbon intensity in output value, and carbon intensity in area for agricultural production over 1995–2016 in Qinghai province.

The changing trend of TCF for agricultural production could be divided into the three time periods of a roughly stable period 1995–1999, a slowly declining period 2000–2007, and a rapidly increasing period 2008–2016 in Qinghai province, which generally synchronized with the periods of before the GFGP, during the GFGP, and after the GFGP, respectively.

The chemical nitrogen fertilizer and energy inputs were the principal influencing factors in the change of the TCF. N fertilizer was the biggest contributor to the TCF and contributed more to the relatively lower TCF over 2000–2007 during the GFGP in the study area. In addition, the relative CF caused by plastic film and diesel in the study area increased faster than that in the whole country. Thus, the potential environmental risks caused by N fertilizer, diesel, and plastic film inputs should be monitored.

The decreasing CV generally synchronized with the increasing CA in Qinghai province. The CV declined, with a mean of 0.022 kg CE/CNY, which was 55.59% of the mean CV in China over 1995–2016; inversely, the CA obviously rose after 2007, with a mean of 5.11 kg CE/ha, which was only 1.94% of the mean CA in China from 1995 to 2016. The agrochemical input intensity during 2005–2007 may be comparatively reasonable to hold a balance between higher carbon efficiency and lower CA. Both CV and CA in the study area were lower than those in China; however, both the carbon efficiency and CA in the study area generally had a higher rate of increase than that in China, which might lead to increasing potential environmental risks in local or downstream regions.

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Conflicts of Interest: We declare no conflict of interest.

References

1. Machado, K.S.; Seleme, R.; Maceno, M.M.C.; Zattar, I.C. Carbon footprint in the ethanol feedstocks cultivation—Agricultural CO_2 emission assessment. *Agric. Syst.* **2017**, *157*, 140–145. [CrossRef]
2. IPCC. *Climate Change 2014: Synthesis Report*; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.
3. Wang, X.H. Changes in CO_2 Emissions Induced by Agricultural Inputs in China over 1991–2014. *Sustainability* **2016**, *8*, 414. [CrossRef]
4. Rowe, R.L.; Street, N.R.; Taylor, G. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renew. Sustain. Energy Rev.* **2009**, *13*, 271–290. [CrossRef]
5. Shen, L.; Gao, T.; Zhao, J.; Wang, L.; Wang, L.; Liu, L.; Chen, F.; Xue, J. Factory-level measurements on CO2 emission factors of cement production in China. *Renew. Sustain. Energy Rev.* **2014**, *34*, 337–349. [CrossRef]
6. Zhao, R.; Huang, X.; Zhong, T.; Peng, J. Carbon footprint of different industrial spaces based on energy consumption in China. *J. Geogr. Sci.* **2011**, *21*, 285–300. [CrossRef]
7. Wang, X. Spatio-temporal changes in agrochemical inputs and the risk assessment before and after the grain-for-green policy in China. *Environ. Monit. Assess.* **2013**, *185*, 1927–1937. [CrossRef] [PubMed]
8. Cheng, K.; Pan, G.; Smith, P.; Luo, T.; Li, L.; Zheng, J.; Zhang, X.; Han, X.; Yan, M. Carbon footprint of China's crop production-An estimation using agro-statistics data over 1993–2007. *Agric. Ecosyst. Environ.* **2011**, *142*, 231–237. [CrossRef]
9. Huang, Z.; Mi, S. Agricultural sector carbon footprint accounting: A case of Zhejiang, China. *Issues Agric. Econ.* **2011**, *11*, 40–47.
10. Dubey, A.; Lal, R. Carbon footprint and sustainability of agricultural production systems in Punjab, India, and Ohio, USA. *J. Crop Improv.* **2009**, *23*, 332–350. [CrossRef]
11. Wu, J.F.; Wang, X.H. Dynamic changes in the carbon intensity and sustainability of farmland use: A case study in Pingdu County, Shandong Province, China. *Acta Ecol. Sin.* **2017**, *37*, 2904–2912.
12. Feng, Z.; Yang, Y.; Zhang, Y.; Zhang, P.; Li, Y. Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* **2005**, *22*, 301–312. [CrossRef]
13. Lin, Y.; Yao, S. Impact of the Sloping Land Conversion Program on rural house hold income: An integrated estimation. *Land Use Policy* **2014**, *40*, 56–63. [CrossRef]
14. Wang, X.; Lu, C.; Fang, J.; Shen, Y. Implications for development of grain-for-green policy based on cropland suitability evaluation in desertification-affected north China. *Land Use Policy* **2007**, *24*, 417–424. [CrossRef]
15. Liu, H. Evolution of Chinese agricultural supporting policies and rural development. *China Agric. Inf.* **2012**, *15*, 24–25.
16. Sun, T. Study of Chinese agricultural policy changes. *J. Anhui Agri. Sci.* **2015**, *43*, 346–348.
17. Wang, X.; Shen, Y. Ecological restoration in West China: Problems and Proposals. *AMBIO* **2009**, *38*, 177–180. [CrossRef] [PubMed]

18. Xiong, C.; Yang, D.; Huo, J. Spatial-temporal characteristics and LMDI-Based impact factor decomposition of agricultural carbon emissions in Hotan prefecture, China. *Sustainability* **2016**, *8*, 262. [CrossRef]
19. Chen, R.; Xu, C.; Deng, Y.; Jiang, Z. Research on low carbon agricultural production modes in Loess Plateau. *J. Northwest A F Univ. (Soc. Sci. Ed.)* **2017**, *17*, 55–65.
20. Hu, A.; Wang, Y. Research on low carbon agriculture development in Sichuan under the background of low carbon economy. *Sichuan Environ.* **2015**, *34*, 110–114.
21. Zhang, J.; Liu, L. Decoupling analysis between agricultural economic development and agricultural production energy consumption in Yunnan. *Environ. Sci. Surv.* **2018**, *37*, 29–34.
22. Si, H.; Yuan, C.; Zhou, W. Effect of land-use on ecosystem service values in Qinghai province. *Agric. Res. Arid Areas* **2016**, *34*, 254–260.
23. Liu, Y. *Investigation Datasets of China Land Resources*; Office of National Land Resources Survey: Beijing, China, 2000.
24. Third Pole Environment Database. Available online: http://www.tpedatabase.cn (accessed on 15 March 2019).
25. National Data, 1995–2016. Available online: http://data.stats.gov.cn (accessed on 15 March 2019).
26. National Bureau of Statistics of China (NBSC). *China Energy Statistical Yearbook, 1996–2017*; China Statistics Press: Beijing, China, 1996–2017.
27. Huo, M.; Han, X.; Shan, B. Empirical Study on Key Factors of Carbon Emission Intensity of Power Industry. *Electr. Power* **2013**, *46*, 122–126.
28. National Development and Reform Commission of China (NDRCC). Guidelines for Provincial Greenhouse Gas Inventories (Trial). Available online: http://www.doc88.com/p-9819327912648.html (accessed on 15 March 2019).
29. Lu, Y.; Huang, Y.; Zou, J.; Zheng, X. An inventory of N_2O emissions from agriculture in China using precipitation-rectified emission factor and background emission. *Chemosphere* **2006**, *65*, 1915–1924. [CrossRef]
30. Lu, F.; Wang, X.; Han, B. Assessment on the availability of nitrogen fertilization in improving carbon sequestration potential of China's cropland soil. Chin. *J. App. Ecol.* **2008**, *19*, 2239–2250.
31. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ); Standardization Administration of the People's Republic of China (SAC). *General Principles for Calculation of the Comprehensive Energy Consumption (GB/T 2589-2008)*; China Standard Press: Beijing, China, 2008.
32. IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; IGES: Tokyo, Japan, 2006.
33. FAOSTAT. 2016. Available online: http://faostat3.fao.org/download/R/RL/E (accessed on 18 March 2019).
34. Wang, X.; Shen, J.; Zhang, W. Emergy evaluation of agricultural sustainability of Northwest China before and after the grain-for-green policy. *Energy Policy* **2014**, *67*, 508–516. [CrossRef]
35. He, J.; Feng, J. The stage features and policy choices in China's agriculture development: A comparative analysis under the perspective of "Four Stages Theory" in international agricultural development process. *Chin. Agric. Sci. Bull.* **2010**, *26*, 439–444.
36. Luan, Y.; Ren, J. Agricultural total factor energy efficiency of China and its convergence. *Chin. J. Agric. Resour. Reg. Plan.* **2014**, *35*, 20–24.
37. Zhang, X. Evaluation of China agriculture energy efficiency based on energy method. *Spec. Zone Econ.* **2014**, *10*, 143–147.
38. Song, J.; Li, Y.; Song, Y.; Yan, J.; Zhou, L. Research and prospect on non-point pollution from agriculture. *Chin. Agric. Sci. Bull.* **2010**, *26*, 362–365.
39. Ismael, M.; Srouji, F.; Mohamed, B.A. Agricultural technologies and carbon emissions: Evidence from Jordanian economy. *Environ. Sci. Pollut. Res.* **2018**, *25*, 10867–10877. [CrossRef]
40. Benbi, D.K. Carbon footprint and agricultural sustainability nexus in an intensively cultivated region of Indo-Gangetic Plains. *Sci. Total Environ.* **2018**, *644*, 611–623. [CrossRef]
41. Baumann, M.; Gasparri, I.; Piquer-Rodríguez, M.; Gavier, P.G.; Griffiths, P.; Hostert, P.; Kuemmerle, T. Carbon emissions from agricultural expansion and intensification in the Chaco. *Glob. Chang. Biol.* **2017**, *23*, 1902–1916. [CrossRef]
42. Wang, X. Agricultural material inputs and the potential risk assessment for vegetable production in China. *J. Resour. Ecol.* **2016**, *7*, 269–274.

43. Yang, S.; Han, R.; Liu, C. Study on the given amount per unit field and load capacity of livestock and poultry manure at provincial scale. *J. China Agric. Univ.* **2016**, *21*, 142–151.
44. Zhu, Z. Loss of fertilizer N from plants-soil system and the strategies and techniques for its reduction. *Soil Environ. Sci.* **2000**, *9*, 1–6.
45. Wang, X. Sustainable development in Tibet requires control of agricultural nonpoint pollution. *Environ. Sci. Technol.* **2014**, *48*, 8944–8945. [CrossRef]
46. Luo, Y.; Long, X.; Wu, C.; Zhang, J. Decoupling CO_2 emissions from economic growth in agricultural sector across 30 Chinese provinces from 1997 to 2014. *J. Clean. Prod.* **2017**, *159*, 220–228. [CrossRef]
47. Jia, B.; Tsau, J.; Barati, R. Role of molecular diffusion in heterogeneous, naturally fractured shale reservoirs during CO_2 huff-n-puff. *J. Pet. Sci. Eng.* **2018**, *164*, 31–42. [CrossRef]
48. Jia, B.; Tsau, J.; Barati, R. A review of the current progress of CO_2 injection EOR and carbon storage in shale oil reservoirs. *Fuel* **2019**, *236*, 404–427. [CrossRef]
49. Plasynski, S.I.; Litynski, J.T.; McIlvried, H.G.; Srivastava, R.D. Progress and New Developments in Carbon Capture and Storage. *Crit. Rev. Plant Sci.* **2009**, *28*, 123–138. [CrossRef]
50. Mi, J.; Ren, J.; Wang, J.; Bao, W.; Xie, K. Ultrasonic and Microwave Desulfurization of Coal in Tetrachloroethylene. *Energy Sources Part A Recovery Util. Environ. Eff.* **2007**, *29*, 1261–1268. [CrossRef]
51. Bui, M.; Adjiman, C.S.; Bardow, A.; Anthony, E.J.; Boston, A.; Brown, S.; Fennell, P.S.; Fuss, S.; Galindo, A.; Hackett, L.A.; et al. Carbon capture and storage (CCS): The way forward. *Energy Environ. Sci.* **2018**, *11*, 1062–1176. [CrossRef]
52. Li, S.; Zhang, Y.; Wang, Z.; Li, L. Mapping human influence intensity in the Tibetan Plateau for conservation of ecological service functions. *Ecosyst. Serv.* **2018**, *30*, 276–286. [CrossRef]
53. Wang, X.; Zhang, H. On the development and utilization of land resources in Hehuang valley in Qinghai province. *New Heights* **2013**, *32*, 113–115.