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EDITED BY
Yuantao Xie,
University of International Business and Economics, China

REVIEWED BY
Xinfa Zhou,
Peking University, China
Siyu Wang,
Shanghai University of International Business and Economics, China

*CORRESPONDENCE
Anqichen Shi,
20180106@lixin.edu.cn

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Setting the Forestry Carbon Sink Insurance compensation standard for reducing losses from forest fires: An empirical study estimating CO_2 emissions from forest fires in a sample of 15 provinces

Huina Lv and Anqichen Shi*

School of Insurance, Shanghai Lixin University of Accounting and Finance, Shanghai, China

Introduction: Forest fires have contributed to increasingly serious global warming by great amount of CO_2 emissions and are seen as a loss of carbon sink value, which could be reduced by compensating economically via the Forestry Carbon Sink Insurance. However, estimating loss of carbon stock by estimating carbon emissions of forest fire losses is a crucial step of calculating the loss of carbon sink value.

Methods: In this research, method proposed by Seiler and Crutzen (1980) was introduced to estimate the carbon emissions as CO_2 by in fifteen sample provinces in China by using official data in 2020, which would provide a scientific expectation in future.

Results: Results show the range of carbon released in the sample provinces and we have estimated for the whole country during 2020——the overall amount of carbon released as CO_2 affected by forest fires reached 35017.42–98486.5t, which can be regarded as a loss of 35017.42–98486.5t of forest carbon sequestration capacity.

Discussion: This study supplies one way of estimating loss of carbon sink value and provides evidence from China that the range of carbon stock loss because of forest fires. In practice, this study supports the forestry authorities to participate in the Forestry Carbon Sink Insurance and provides empirical data to establish compensation standards for insurance companies.

KEYWORDS

Forestry Carbon Sink Insurance, forest fires, biomass burning, carbon emissions released as CO_2, set compensation standard for reducing the loss

1 Introduction

Climate change is a great challenge to the survival and development of mankind and a major global issue of common concern to the international community (Tigchelaar et al., 2018; Liu W. et al., 2022). The international community has reached a consensus on tackling global climate change through "carbon neutrality" (Lin et al., 2021; Zhang et al., 2021; Qin et al., 2022). In 2020, China officially put forward the goal of achieving a "carbon peak" in emissions by 2030, and striving for the strategic goal of "carbon neutrality" by 2060 (hereinafter referred to as the goal of "dual carbon").

Forest has a strong carbon sequestration function of absorbing and storing carbon dioxide. Therefore, it is considered an important way to deal with global climate change by enhancing forestry carbon sink capacity to neutralize greenhouse gas emissions and has obvious cost advantages (Phan, Brouwer, and Davidson, 2014; Ma et al., 2020; Lin et al., 2021; Zhang et al., 2021).

The national policy level also strongly supports the green development path of forestry carbon sequestration. Forestry carbon sinks should be included in the national carbon trading market as a priority (National Development and Reform Commission, 2019), and we should accelerate the improvement of pricing, fiscal, tax, financial, and other economic policies conducive to green and low-carbon development (Lu, H., 2022). Furthermore, we should also actively yet prudently promote carbon peaking and carbon neutrality and improve the statistical accounting system of carbon emissions, improve the market trading system of carbon emission rights, and enhance the capacity of carbon sequestration in the ecosystem (Xi, J. P., 2022). With the gradual strengthening of the national carbon emission trading regulations, the ecological service of the forest itself to absorb and store carbon dioxide has realized a surplus value beyond the direct economic value (Lin et al., 2021).

However, due to the long forestry development cycle, the forestry carbon sink is faced with great uncertainty as the realization of such value is confronted with the risk of loss of many carbon assets and the risk of loss of the carbon sink during the growth of the carbon sequestration forest. Forestry Carbon Sink Insurance is an effective economic measure specifically for the management of such uncertain risks. According to it, if forest trees were damaged during the insurance period due to natural disasters agreed in the insurance contract (such as fire, debris flow, and forest pests and diseases) and the value of forestry carbon sink reduction had reached the standard of compensation after professional calculation by the insurance company, the insurance company would investigate and determine the loss together with the competent forestry authorities, and pay a compensation as per the contract (Wang, 2022). Forestry Carbon Sink Insurance can effectively compensate for losses caused by various kinds of risks and plays an important role in supporting forestry carbon sink and carbon emission trading.

Forest fires have the most extensive and frequent natural disaster risk. According to the data in the China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/2021/index), there were 1,153 forest fires in China in 2020 alone, covering a total area of 25,081 ha, with 41 casualties and economic losses of 100.777 million yuan. Among them, there were two provinces with economic losses of more than 10 million yuan. There were 111 forest fires in Sichuan, three of which were classified as major fires. The economic losses amounted to 55.035 million yuan, accounting for that of half the country. There were 17 forest fires in Shanxi, including one major fire, which resulted in an economic loss of 14.823 million yuan. However, these local forestry authorities did not have Forestry Carbon Sink Insurance, which made the loss of forest carbon sink capacity unable to be compensated.

Given the above, this study focuses on the impact of forest fires on forest carbon sequestration ability. By estimating forest fire carbon emission data, we can reasonably convert the forest loss into forest carbon sequestration loss to calculate the loss of carbon sink value. This measure is helpful to overcome the deficiency of traditional comprehensive forest insurance, which only compensates for the property loss of forest trees and the direct material cost loss of seedling planting. It effectively compensates for indirect losses including the surplus value of carbon sink, which helps to build a compensation mechanism for the damage of elements in the carbon trading market. More importantly, the pre-estimation of forest carbon sink losses caused by forest fires will become important reference data for potential insurance subjects, such as state-owned forest farms, state-owned enterprises, district governments, or forestry authorities, to decide whether to insure or how much to invest in Forestry Carbon Sink Insurance, which is of great significance to the realization of the "dual carbon" goal.

Against this background, this study is aimed at estimating loss of carbon stock by calculating the carbon emissions as CO_2 of forest fires. In the research, this study is based on the method proposed by Seiler and Crutzen (1980) and estimated the carbon emissions as CO_2 losses in the 15 sample provinces by using the data of forest fires from NBS, forest biomass in *China Forest Resources Report (2014–2018)* and the burning efficiency ranges from derivation and adjustment from other documentation. Our findings show the range of carbon released in the sample provinces and we have estimated for the whole country during 2020, the overall amount of carbon released as CO_2 affected by forest fire reached 35017.42–98486.5t, which can be regarded as a loss of 35017.42–98486.5t of forest carbon sequestration capacity.

The contribution of the article is that we supply one method of estimating loss of carbon sink value and provide evidence from China that the range of carbon emissions of forest fire losses. In practice, the calculation can not only support the forestry authorities in each province when participating in Forestry Carbon Sink Insurance but also provide empirical data for insurance companies to set compensation standards.

The remainder of the paper is structured as follows: Section 2 provides a literature review; Section 3 introduces research materials and methods; Section 4 presents the empirical results; Section 5 concludes.

2 Literature review

In terms of forest insurance and carbon emissions from forest fires, Wolfgang and Paul (1980) calculated the global fire-affected biomass by using research model proposed by Crutzen et al. (1979), summarized the overall impact of the biosphere on atmospheric carbon dioxide, and proposed a method for measuring the amount of fuel lost by forest fires. Tian et al. (2003) estimated the carbon released directly from forest fires in China and found that the average annual CO_2 emission from 1991 to 2000 accounted for 2.7%–3.9% of China's total emissions (calculated in 2000), and CH_4 emission accounted for 3.3%–4.7%. Leng et al. (2011) proposed the definition of the development mode of forest insurance and its five-O analysis framework. In addition, a technical method for insurance rate determination based on quantitative risk assessment of forest fires was developed on the provincial scale and the hectare grid scale respectively. Zhang et al. (2016) analyzed the regional distribution of the net rate of forest fire insurance, providing a reference for a comprehensive and scientific determination of forest fire insurance rates.

Regarding Forestry Carbon Sink Insurance, Song et al. (2019) built a Stackelberg game model to study the optimal strategies of forestry enterprises and insurance companies under the forest insurance mechanism, as well as the factors affecting their decisions and profits. Feng et al. (2021) put forward policy suggestions on addressing climate change from various aspects based on the climate change risk situation in China and the development stage of green insurance services. Zhang et al. (2021) proposed that forestry carbon sink was recognized as a natural solution to climate change and an important way to achieve "carbon neutrality". To achieve global net zero emissions of greenhouse gases, it was necessary to give full play to the carbon offset role of forestry carbon sink. Lin et al. (2021) took the first Forestry Carbon Sink Index Insurance in China as an example to analyze the innovative exploration of the establishment of policy insurance mechanisms establishing the surplus value of forestry carbon sinks. Qin et al. (2022) sorted out four kinds of Forestry Carbon Sink Insurance products in China at the present stage and pointed out the following problems, such as unclear object of insurance, unreasonable insurance amount setting, incomplete insurance liability, unscientific rate pricing, and failure to give full play to risk compensation. Qin et al. (2022) conducted an in-depth analysis of the development opportunities, content composition, and path selection of forestry carbon sinks in China and identified bottlenecks and priorities in the current development of forestry carbon sinks. Wang et al. (2022) believed that there were differences in forest carbon sink capacity in different regions, and it would be difficult to promote Forestry Carbon Sink Insurance from pilot to nationwide in the future.

Overall, researchers thoroughly investigated forest fire carbon loss and forest insurance, but few studies directly combine the impact of forest fires on carbon sequestration capacity with the development of carbon sink insurance. Therefore, based on existing research results, we estimated the range of burning efficiency of ecosystems in 15 sample provinces with the highest forest fire losses by using data on forest fires and forest biomass in China in 2020. We finally calculated the carbon emissions as CO_2 of forest fire losses in fifteen sample provinces.

3 Materials and methods

3.1 Research materials

Considering the available data from the National Bureau of Statistics (NBS) (http://www.stats.gov.cn/), we selected the top 15 provinces as our samples based on the amount of loss discount by forest fires. The samples selected for this study are representative administrative regions with vast forest areas that have been affected by forest fires to some extent every year.The sample provinces are relatively complete, as they covered the major forest resources and accounted for almost half of the provinces in China, including the pilot province, Fujian, where Forestry Carbon Sink Insurance was launched.

Specifically, in descending order of the amount of loss discount by forest fires, these 15 sample provinces are Sichuan, Shanxi, Guangdong, Jiangxi, Yunnan, Hebei, Guangxi, Inner Mongolia, Gansu, Hunan, Fujian, Tibet and Hainan, Zhejiang, Guizhou. The amount of loss in all sample provinces was above 500,000 yuan in 2020 (as shown in Figure 1).

This study estimated carbon emissions from forest fires in 15 sample provinces in China in 2020. The data in this study were obtained from the China Statistical Yearbook (National Bureau of Statistics, 2021) on the website of National Bureau of Statistics (NBS) (http://www.stats.gov.cn/) and the government website of *the State Forestry and Grassland Administration* (http://www.forestry.gov.cn/), and also cited data from *the China Forest Resources Report 2014–2018* (SFA, 2019) on the survey of dominant forest species and stockpiles in each province of China, and referred to the book named *Fire, climate change, and carbon cycling in the boreal forest* written by Eric S.K & B.J. Stocks (2000).

3.2 Research methods

The research method in this study is based on a carbon emission measurement model proposed by Crutzen et al. (1979), that is, the total amount of biomass M burned annually in a biome is approximately given by the equation:

$$M = A^{*}B^{*}\beta^{*}\mathrm{E}, \tag{1}$$

Where M is the biomass consumed by ecosystem burning (t); A is the total land area burned annually (hm^2), B is the total biomass per unit area in the individual biomes (t/hm^2), β is the rate of above-ground biomass present in the ecosystem, and E is the burning efficiency of the above-ground biomass.

The total release of carbon accounts for a% of biomass released by ecosystem burning, which is given by the equation:

$$M(C) = M^{*}a\% \tag{2}$$

In addition, during complete combustion, the burning of biomass produces carbon dioxide (CO_2). According to Andreae (1991), 90% of the carbon is released as CO_2, so the amount of carbon contained in CO_2 released by fire can be calculated by the equation:

$$M(CO_2) = 0.9^{*}M(C). \tag{3}$$

It is known that approximately 25% of the total biomass is stored in the roots of plants, being hardly attacked by fire. Furthermore, only part of the biomass exposed to fires is burned. Combining these facts, and based on the findings of Andreae (1991), Levine (2003), and Pino-Cortés et al. (2022), this study follows the assumptions for common values: above-ground biomass is present in the ecosystem at a rate of 75% as exposed to the forest fire (that is, $\beta = 75\%$), burning efficiency is calculated as a representative range by typical forest trees in each region in combination with fire intensity; the average carbon is present in the ecosystem at a rate of 50% (that is, $a = 50\%$), and only carbon emissions released as CO_2 are calculated.

4 Results

4.1 Forest fire characteristics in the fifteen sample provinces in 2020

The frequency and intensity of fire disasters will affect the amount of forest, that is, completely or incompletely burned. By comprehensive consideration of these two elements, the forest fire risk frequency and risk intensity, we classified these provinces into different grades (high, middle, and low risk). Therefore, provinces such as Sichuan, Guangdong, Guangxi, and Inner Mongolia belonged to the high-risk grade; provinces such as Shanxi, Jiangxi, Yunnan, Hunan, Fujian, and Hainan were classified into the middle-risk grade; and other provinces such as Hebei, Gansu, Tibet, Zhejiang, and Guizhou were considered as low-risk grade (as shown in Figure 2 and Table 1).

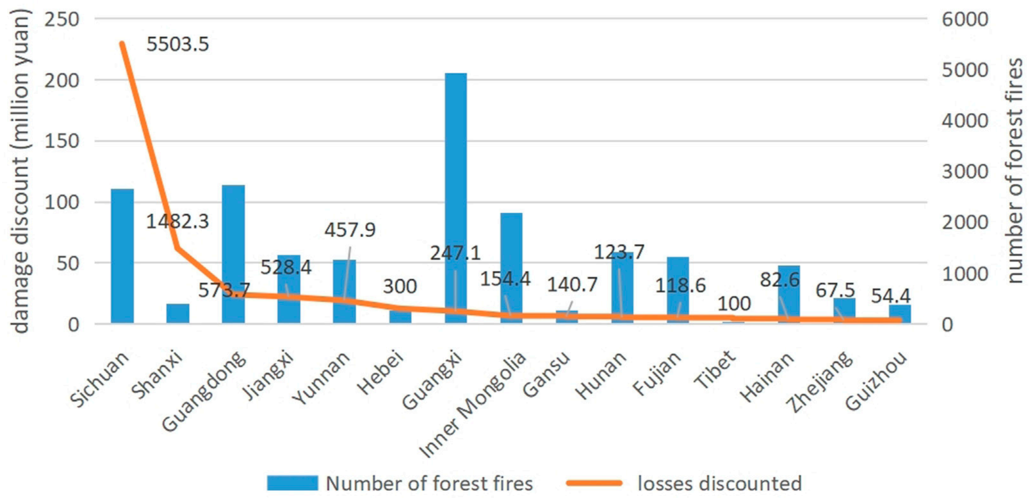

FIGURE 1
Discounted losses due to forest fires in the sample provinces in 2020 (based on losses ordered from largest to smallest). Note: The primary axis is the damage discount (million yuan) and the secondary axis is the number of forest fires.

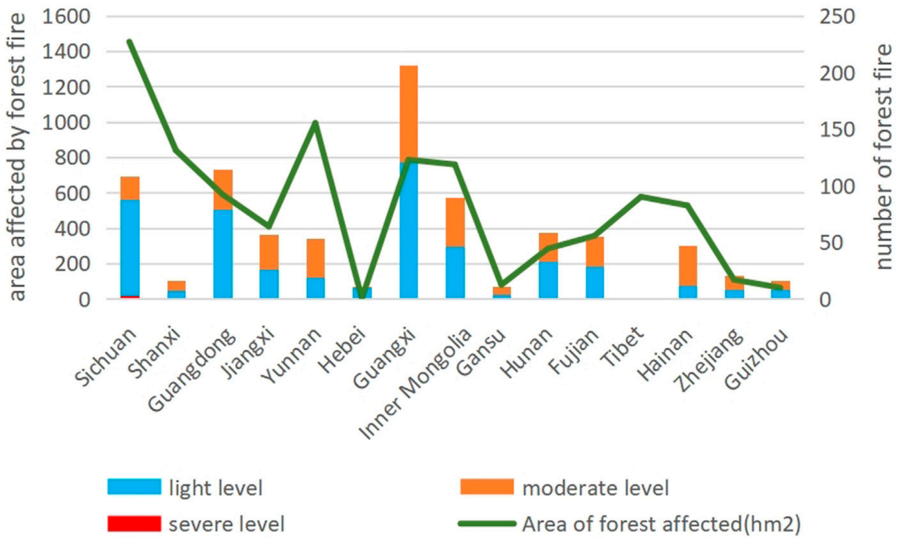

FIGURE 2
the area affected by forest fires and the number of forest fires in the sample provinces in 2020. Note: In Figure 2, the main axis shows the area affected while the secondary axis shows the number of different levels of fires affected. According to both fire characteristics in sample provinces we classify them into three grades.

4.2 Forest biomass load of the 15 sample provinces in 2020

The fuel load per unit area of various provincial forests includes above-ground and underground parts. The above-ground biomass mainly includes trees (stem, branches, bark, and leaves), shrubs, herbs, dead branches and leaves, humus and coarse woody residues, *etc.* We collected the amount of total forest biomass and total carbon stock, and the total forest area of these sample provinces through *the China Forest Resources Report 2014–2018* from the Fifth Forest Census, as shown in Figure 3. Furthermore, we estimated the amount of above-ground biomass per unit area through a simple calculation, in which the above-ground biomass per unit area accounted for 75% of the total forest biomass, as shown in Table 2.

4.3 The burning efficiency range of above-ground forest biomass in 15 sample provinces in 2020

The locations of forests in these sample provinces are different, which include tropical, temperate, and boreal forests. Due to the incomplete data, this study reviewed previous documentation and

TABLE 1 Fire risk grades of sample provinces.

The grades of provinces in forest fire risk (the grade of provinces is a comprehensive consideration of the two elements, that is, risk frequency and risk intensity, in column 2 and column 3 respectively)	Frequency of forest fires (it could be simply seen as the height of the histogram in Figure 2)	Fire risk intensity of forest (it could be simply seen as the contribution of red and orange bars in the histogram in Figure 2)	The classification of sample provinces
High-risk grade	high	Severe level	Sichuan, Guangdong, Guangxi, and Inner Mongolia
Meddle-risk grade	middle	Moderate level	Shanxi, Jiangxi, Yunnan, Hunan, Fujian, and Hainan
Low-risk grade	low	Light level	Hebei, Gansu, Tibet, Zhejiang, and Guizhou

Note: Column 2 is the frequency of forest fires, which could be simply seen as the height of the histogram in Figure 2. Column 3 is the fire risk level of the forest, which could be simply seen in Figure 2 as the contribution of red and orange bars in the histogram. We obtained the fire grades of each province through a comprehensive consideration of these two elements.

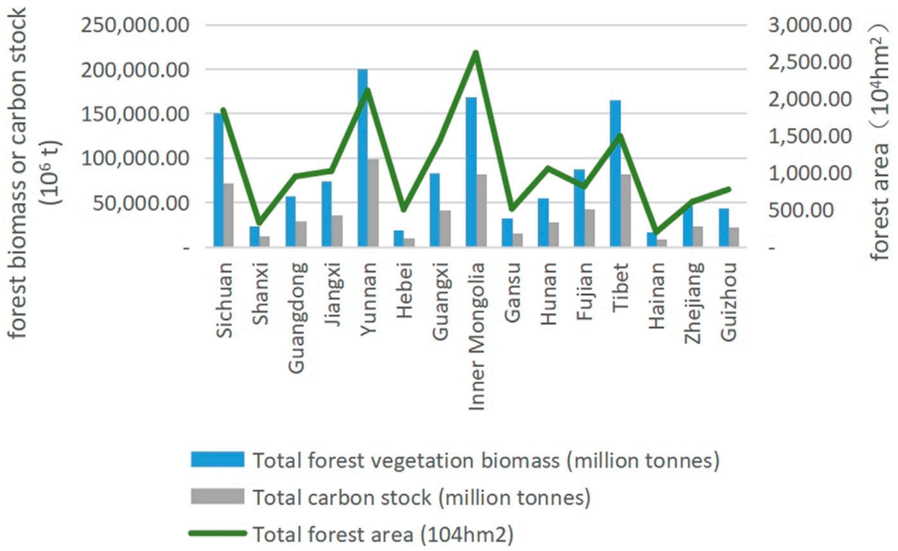

FIGURE 3
Forest characteristics of the sample provinces. Data source: *China Forest Resources Report 2014–2018*, China Forestry Press, 2019 (5). Note: Figure 3 represents the forest characteristics of the sample provinces, with the primary axis showing the total forest biomass and total carbon, both in million tons, and the secondary axis showing the forest area, in million hectares.

obtained the following burning efficiency range of different forests, as shown in Table 3.

The most uncertain parameter in Eq. 1 is the burning efficiencies of the above-ground forest biomass. In this study, to increase the reliability of our estimation, we preferred the range of burning efficiency to the average burning efficiency of above-ground forest biomass in the 15 sample provinces, as shown in Column 5 of Table 4. The ranges of burning efficiency were estimated by combining the fire risk levels of each province and the burning efficiency range of the different vegetation zones of each sample province, as shown in Table 3.

The estimation of the burning efficiency range was performed in the following steps. Firstly, the range of burning efficiency of the forest system in the specific province falls in the higher, middle, or lower part of the overall range classification depending on the different grades of provinces (which is shown in Table 1). And then, to make this estimate more reliable, we adjust this range to correspond to estimations by different authors that could be found in other studies (Hu et al., 2012; Feng et al., 2021; Lin et al., 2021; Zhang et al., 2021; Liu et al., 2022).

Take Inner Mongolia as an example, the estimation of the burning efficiency range was performed like this. Firstly, The Inner Mongolia forests are boreal forests as the lattitude is high and the average temperature is very cold, so the range of burning efficiency of the forest system is likely to be in the range of (0.26–0.46) to correspond to the burning efficiency range of different forests in table 3. Next, Inner Mongolia belonged to the high-risk grade according to the frequency and intensity of fire disasters (as shown in Table 1). Therefore, the range of burning efficiency of the forest system in Inner Mongolia was regarded as in the higher part of the overall range classification

TABLE 2 Forest biomass in the fifteen sample provinces in 2020.

Provinces	Total forest area (10^4hm^2)	Total forest biomass (10^6 t)	Above-ground biomass (10^6t)	Above-ground biomass per unit area (t/hm^2)
Sichuan	1,839.77	150,386.79	112,790.09	61.31
Shanxi	321.09	23,058.30	17,293.73	53.86
Guangdong	945.98	57,504.61	43,128.46	45.59
Jiangxi	1,021.02	73,483.94	55,112.96	53.98
Yunnan	2,106.16	200,198.35	150,148.76	71.29
Hebei	502.69	18,952.42	14,214.32	28.28
Guangxi	1,429.65	82,882.95	62,162.21	43.48
Inner Mongolia	2,614.85	168,103.75	126,077.81	48.22
Gansu	509.73	32,302.10	24,226.58	47.53
Hunan	1,052.58	55,076.73	41,307.55	39.24
Fujian	811.58	87,296.84	65,472.63	80.67
Tibet	1,490.99	165,161.88	123,871.41	83.08
Hainan	194.49	16,732.48	12,549.36	64.52
Zhejiang	604.99	46,210.97	34,658.23	57.29
Guizhou	771.03	43,671.14	32,753.36	42.48

Source: The first two columns of data are from *China Forest Resources Report 2014-2018*, China Forestry Press, 2019 5); the third column represents the above-ground biomass, accounting for 75% of the total biomass; and the fourth column represents the above-ground biomass per unit area.

TABLE 3 The burning efficiency range of different forests.

Above-ground biomass	Locations of forests	Overall burning efficiency	Specific sample provinces	Ref
trees (stem, branches, bark, and leaves), shrubs, herbs, and on-ground vegetation (dead branches and leaves, humus, and coarse woody residues)	Tropical, subtropical forests	0.20–0.43	Hainan, Guangdong, Guangxi, Yunnan	Andreae (1991); Crutzen et al. (1979)
	Temperate, warm temperate forests	0.22–0.44	Sichuan, Shanxi, Jiangxi, Hunan, Fujian, Hebei, Gansu, Zhejiang, and Guizhou	Wolfgang & Paul (1980); Tian et al. (2003)
	Boreal forest, Tibet forests	0.26–0.46	Inner Mongolia and Tibet	Aulair A.N.D. and T.B. Carter. (1993)

(0.26–0.46). Last but not least, due to the incomplete data, this study reviewed previous documentation (Hu et al., 2012; Tian et al., 2003; and so on) and adjusted the burning efficiency range of Inner Mongolia forests (0.35–0.41), as shown in Column 5 of Table 4.

4.4 Calculation of carbon emissions released as CO_2 from forest fires

Based on Eq. 3, the carbon emissions released as CO_2 can be estimated by the above-ground forest biomass exposed to forest fires in 15 provinces in 2020. We estimated the biomass loss range caused by forest fires, as shown in Table 4.

For the whole country, the total area affected by forest fire reached 8526 hm^2 in 2020. The average above-ground forest biomass was approximately 57.04 t/hm^2. The average burning efficiency was estimated as 0.16–0.45. Therefore, the overall amount of carbon released as CO_2 affected by forest fire reached 35017.42–98486.5t, which can be regarded as a reduction of 35017.42–98486.5t of forest carbon sequestration capacity.

5 Conclusion

With the improvement of technology and big data applications, we can avoid disasters and reduce the number of forest fires to a certain extent, but the annual forest fire disasters caused by lightning or human inappropriate behaviors are still very serious. In these circumstances, the Forestry Carbon Sink Insurance is necessary and the standard of compensation by the insurance is needed. Therefore, it would be much more valuable economically to accurately quantify the carbon sequestration capacity.

This study is aimed at estimating the carbon emissions as CO_2 of forest fire losses. Based on the method proposed by Seiler and Crutzen (1980), this study estimated the carbon emissions as CO_2 losses in the 15 sample provinces by using the data of forest fires from NBS, forest

TABLE 4 Estimation of carbon emissions from forest fires in sample provinces in 2020.

Sample provinces	Typical forest	Forest affected area (hm^2)	Average above-ground biomass (t/hm^2)	Burning efficiency range	Amount of carbon contained in CO_2 released by fire(t)
Sichuan	Fir forest	1453	61.31	0.35–0.42	14029.87–16835.84
Shanxi	Yaupon forest	839	53.86	0.33–0.38	6710.43–7727.16
Guangdong	*Eucalyptus* forests	591	45.59	0.31–0.40	3758.75-4850
Jiangxi	Fir forest	409	53.98	0.24–0.35	2384.33–3477.15
Yunnan	Yunnan pine forests	993	71.29	0.28–0.37	8919.7–11786.74
Hebei	Oak forests	3	28.28	0.23–0.32	8.78–12.22
Guangxi	*Eucalyptus* forests	786	43.48	0.30–0.38	4613.74–5844.07
Inner Mongolia	Larch forests	759	48.22	0.35–0.41	5763.87–6751.96
Gansu	*Acacia* forests	79	47.53	0.24–0.31	405.51–523.79
Hunan	Fir forest	284	39.24	0.26–0.34	1304–1705.23
Fujian	Fir forest	356	80.67	0.27–0.36	3489.43–4652.58
Tibet	Spruce forests	577	83.08	0.23–0.38	4961.49–8197.25
Hainan	Rubber forests	528	64.52	0.25–0.35	3832.75–5365.85
Zhejiang	Fir forest	108	57.29	0.22–0.31	612.52–863.09
Guizhou	Fir forest	63	42.48	0.24–0.35	289.03–421.51

Sources: the data in Column 3 was directly from the China Statistical Yearbook 2021, the numbers of average above-ground biomass in Column 4 were obtained from the calculations in Table 2, and the ranges of burning efficiency in Column 5 were estimated in accordance with fire intensity and the burning efficiency of different vegetation zones.

biomass in *China Forest Resources Report (2014–2018)* and the burning efficiency ranges from derivation and adjustment from other documentation. In practice, the calculation can support the forestry authorities in each province when participating in Forestry Carbon Sink Insurance and provide empirical data for insurance companies to set compensation standards.

Nevertheless, our study still has some limitations, as follows.

First, total carbon emissions as CO_2 from forest fires were roughly calculated in this study, which might be underestimated compared to the actual emissions, mainly because only the above-ground forest biomass (trees, shrubs, herbs, dead leaves, humus, and coarse woody debris) was considered in the calculation of forest fire burning losses, while the contributions of the roots underground were ignored. So, more data are needed to make these estimates more reliable.

Second, since the influencing factors of the carbon emissions in the ecosystems are comprehensive and objective, this study only employed influencing factors such as tree species and vegetation zones and it was difficult to consider many other factors such as tree age, diameter at breast height, and density of vegetation itself, as well as environmental factors such as sunlight, temperature, and precipitation.

Third, this study only took big-scale forest areas into account. But many other small-scale forests also need to be considered since their owners are the potential consumers of the Forestry Carbon Sink Insurance.

Fourth, this study only studied the CO_2 emissions of one-time affected trees and didn't consider trees that were not completely destroyed or recovered to a certain extent after the disasters, which should also be included in the insurance liability to verify their true surplus value and provide reasonable insurance payouts information to insurance companies.

In summary, we believe that Forestry Carbon Sink Insurance will play an important role in the process of the construction of regional and national climate measurement and monitoring systems. Only by calculating the carbon sink capacity more exactly can we set more suitable standards for insurance amounts and premium rates of the Forestry Carbon Sink Insurance. We also need to promptly respond to forest fire accidents and effectively protect the consumers' rights of Forestry Carbon Sink Insurance. (National Bureau of Statistics, 2021; SFA, 2019).

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

HL contributed to conception and AS performed the statistical analysis. Both authors contributed to manuscript revision and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Andreae, M. O. (1991). "Biomass burning: Its history, use, and distribution and its impact on environmental quality and global climate," in *Global biomass burning: Atmospheric, climatic, and biospheric implications*. Editor J. S. Levine (Cambridge, MA, USA: MIT Press), 3–21.

Aulair, A. N. D., and Carter, T. B. (1993). Forest wildfires as a recent source of CO_2 at northern latitudes. *Can. J. For. Res.* 23, 1528–1536. doi:10.1139/x93-193

Crutzen, P., Heidt, L., Krasnec, J., Pollock, W. H., and Seiler, W. (1979). Biomass burning as a source of atmospheric gases CO, H_2, N_2O, NO, CH_3Cl and COS. *Nature* 282, 253–256. doi:10.1038/282253a0

Eric, S. K., and Stocks, B. J. (2000). *Fire, climate change, and carbon cycling in the boreal forest*. New York, NY, USA: Springer.

Feng, A. Q., Yue, X. L., Chao, Q. C., and Wang, G. F. (2021). China's climate change risk and green insurance response under the goal of carbon peaking and carbon neutrality. *Environ. Prot.* 8, 20–24. doi:10.14026/j.cnki.0253-9705.2021.08.004

Hu, H. Q., Wei, S. H. J., and Sun, L. (2012). Estimation of carbon emissions due to forest fire in Daxing'an Mountains from 1965 to 2010. *J. Plant Ecol.* 36 (07), 629–644. doi:10.3724/sp.j.1258.2012.00629

Leng, H. Q. (2011). *Study on forest fire risk assessment and insurance rate determination in China*. Beijing, China: Tsinghua University. [Dissertation].

Levine, J. S. (2003). Biomass burning: The cycling of gases and particulates from the biosphere to the atmosphere. *Treatise geochem.*, 143–158. doi:10.1016/b0-08-043751-6/04143-8

Lin, Q. D., Lou, F., Sun, C. F., Huang, Z. L., Li, M. Y., and Sun, Q. (2021). Innovation and exploration of insurance industry's involvement in forestry carbon sequestration -- A case study of the first forestry carbon sequestration index insurance in China. *Fujian Finance* 6, 36–41.

Liu, W., Zhan, J., Zhao, F., Wang, C., Zhang, F., and Teng, Y., (2022). Spatio-temporal variations of ecosystem services and their drivers in the pearl river delta, China. *J. Clean. Prod.* 337, 130466. doi:10.1016/j.jclepro.2022.130466

Lu, H. (2022). We will comprehensively promote the modernization of harmonious coexistence between man and nature. https://m.gmw.cn/baijia/2022-06/03/35785758.html (Accessed on November 20, 2022).

Ma, W. W., and Zhao, S. A. (2020). Research on the development and problems of financial service forestry carbon sink. *Southwest Finance* 6, 46–55.

National Bureau of Statistics (2021). China statistical Yearbook. Beijing: China Statistics Press. http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm (Accessed on November 20, 2022).

National Developmentand Reform Commission of China, (2019). Notice on the issuance of the action plan on establishing a market-based and diversified ecological protection compensation mechanism. http://www.gov.cn/xinwen/2019-01/11/content_5357007 (Accessed on November 29, 2022).

Phan, T. H. D., Brouwer, R., and Davidson, M. (2014). The economic costs of avoided deforestation in the developing world: A meta-analysis. *J. For. Econ.* 20 (1), 1–16. doi:10.1016/j.jfe.2013.06.004

Pino-Cortés, E., Carrasco, S., Díaz-Robles, L. A., Cubillos, F., Vallejo, F., and Cereceda-Balic, F., (2022). Emission inventory processing of biomass burning from a global dataset for air quality modeling. *Air Qual. Atmos. Health.* 15, 721–729. doi:10.1007/s11869-021-01129-0

Qin, G. W., and Tian, M. H. (2022). Development opportunity and implementation path of forestry carbon sequestration under "double carbon" target. *Reform Admin* 01, 45–54. doi:10.14150/j.cnki.1674-7453.2022.01.008

Qin, T., Li, H., and Song, R. (2022). On the model comparisons, constraints and optimization strategies of forestry carbon sink insurance. *Rural. Econ.* 3, 60–66.

SFA (2019). *China forest resources Report (2014-2018)*. Beijing, China: State Forestry Administration of China: China Forestry Press.

Song, Y., and Peng, H. J. (2019). Strategies of forestry carbon sink under forest insurance and subsidies. *Sustainability* 11 (17), 4607. doi:10.3390/su11174607

Tian, X. R., Shu, L. F., and Wang, M. Y. (2003). Estimation of carbon emission from forest fires in China from 1991 to 2000. *Sci. Fire* 1, 6–10.

Tigchelaar, M., Battisti, D. S., Naylor, R. L., and Ray, D. K. (2018). Future warming increases probability of globally synchronized maize production shocks. *Proc. Natl. Acad. Sci. U. S. A.* 115 (26), 6644–6649. doi:10.1073/pnas.1718031115

Wang, F. Q. (2022). Forestry carbon sequestration insurance is developing rapidly. *China's Insur. Quote.* doi:10.28049/n.cnki.ncbxb.2022.003454

Wolfgang, S., and Paul, J. C. (1980). Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. *Clim. Change.* 2 (3), 207–247. doi:10.1007/bf00137988

Xi, J. P. (2022). Holding high the great banner of socialism with Chinese characteristics and striving together to build a modern socialist country in all respects -- Report delivered at the 20th national congress of the communist party of China. http://www.gov.cn/xinwen/2022-10/25/content_5721685.htm (Accessed on November 20, 2022).

Zhang, D. C., Chen, S. Z., and Bai, D. Y. (2016). Model and Empirical analysis of net rate determination for forest fire insurance. *Sci. For.* 7, 129–137.

Zhang, Y., Li, F., and Li, Y. (2021). Research on forestry carbon sink Market and Forestry carbon sink trading in Hainan under the background of carbon neutrality. *Humanit. Soc. Sci. J. Hainan Univ.* 3, 35–43. doi:10.15886/j.cnki.hnus.20210318.001