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Potential of Agroforestry to Provide Wood Resources to Central Asia

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Abstract: Background: Agroforestry systems have the potential to provide timber and wood as a domestic raw material, as well as an additional source of income for rural populations. In Central Asia, tree windbreaks from mainly poplar trees have a long tradition, but were largely cut down as source for fuel wood after the disintegration of the Soviet Union. As Central Asia is a forest-poor region, restoration of tree windbreaks has the potential to provide timber and wood resources to that region. This study aimed to assess the potential of tree windbreaks to contribute to domestic timber and wood production. Methods: This study rests on a GIS-based analysis, in which tree lines (simulated by line shape files) were intersected with cropland area. The tree data to calculate timber and wood volumes stem from a dataset with 728 single trees from a relevant range of climatic conditions. Results: The potential annually available timber volumes from tree windbreaks with 500 m spacing are 2.9 million m^3 for Central Asia as a whole and 1.5 million m^3 for Uzbekistan alone, which is 5 times the current domestic roundwood production and imports of the country. Conclusions: tree windbreaks offer untapped potential to deliver wood resources domestically as a raw material for wood-based value chains.

Keywords: fast growing trees; tree windbreak; poplar; irrigated agriculture; remote sensing; GIS; timber volume; fuel wood

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1. Introduction

It is widely recognized that agroforestry provides a number of benefits directly to land users and indirectly to society [1–3]. Thereby, agroforestry is understood as land use systems in which woody perennials (trees and shrubs in the case of Central Asia) are deliberately used on the same land as crops or animals [4]. Trees on farms provide an additional source of income from timber, fruits, fodder, or fuel wood [5,6]. Those trees also store carbon in their biomass and increase carbon sequestration [7,8]. In this way, agroforestry contributes to the mitigation of climate change and has been listed as a major land-based carbon removal technique [8]. An expansion of agroforestry systems does not replace ongoing land uses, so conflicts over land that may occur in the context of afforestation projects are less likely to be instigated. Therefore, IPCC [9,10] listed agroforestry among the land management practices that substantially contribute to climate change mitigation, while not compromising food supply.

In a large number of contexts, trees on farms help to increase crop yields, mainly because the microclimate is improved [11]. Windspeed and evapotranspiration are reduced, while temperature extremes are moderated [12]. Therefore, agroforestry, especially in arid or semi-arid regions, contributes to climate change adaptation as well. In particular, tree windbreak systems do reduce wind speed, which substantially reduces evapotranspiration and water consumption of agriculture in drylands [12–17].

Tree windbreaks are the major agroforestry system in Central Asia, in particular across the irrigated agriculture of that region. According to the definition of agroforestry [4], such trees were planted along field boundaries with a clear purpose to reduce the wind speed and provide timber in a forest poor region. The cropland in Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan is significantly dependent on irrigation, due to the arid climate in the cropland regions of those countries. According to FAOSTAT [18], in Kyrgyzstan and Tajikistan, 69% and 87% of the cropland are irrigated, respectively. In Turkmenistan and Uzbekistan, more than 95% of all cropland is equipped with irrigation. As the source for the irrigation water are the rivers, that cropland is concentrated along those rivers, with the Amu Darya, Syr Darya, Chui, Ili, and Talas being the major ones. In Kazakhstan, irrigated land is concentrated in the southern part of the country, which are the provinces Almaty, Zhambul, and South Kazakhstan as well as Qyzylorda along the Syr Darya River.

Tree lines along field boundaries, which actually serve as tree windbreaks, have a long tradition across Central Asia. Those tree lines mainly consisted of *Populus nigra* trees. During the period of the Soviet Union, tree windbreaks were strongly promoted [13,14,19,20]. After the collapse of the Soviet Union, trade between the Republics was largely interrupted; especially energy supply to rural communities dropped severely. Therefore, substantial parts of the tree windbreaks were felled, because people needed to use wood as fuel. Today, this pressure on tree windbreaks has decreased across Central Asia, most prominently in Kazakhstan and Turkmenistan, countries that have large gas and oil reserves and were able to provide gas to rural areas faster than the other countries [21]. Farmers' perception of tree windbreaks and willingness to establish them anew differs between communities and ranges from unwillingness to establish such tree windbreaks in some communities to acceptance by a majority of farmers in other villages, who believe there to be lots of benefits from tree windbreaks [22].

In the Central Asian climate, tree windbreaks reduce the crop water consumption and the whole systems of crops with tree windbreaks consume less water than crops without tree windbreaks [17]. The total income from systems of crops with tree windbreaks over longer time periods was found to be higher than the income from crops without tree windbreaks over the same time period [23]. These findings suggest that tree windbreaks should be restored and expanded across the countries of Central Asia, which is in line with political strategies of the countries, such as strategies in the field of green economy, forest restoration and sustainable land use, as well as the commitments under the Bonn Challenge, as reviewed in UNECE/FAO [21].

All five countries of Central Asia are forest poor countries, with forest covers below 10% [24] and must import large quantities of wood to meet their demand for timber and fuel wood. Trees on farms could contribute to domestic wood harvest and help to meet domestic wood demand. Against this background, this study aims at exploring the potential of tree windbreak systems as the major agroforestry system in the region of Central Asia to contribute to domestic wood production. Thereby, this study aims at assessing the potential amounts of timber and fuel wood that could be harvested sustainably from tree windbreak systems of the dominant *P. nigra* cultivars, if they were established across all available cropland under irrigated agriculture. So, the result of this study will mark an upper limit of timber and fuel potentially harvested from tree windbreaks, which may provide insights into the opportunities for the region of Central Asia offered by agroforestry.

2. Materials and Methods

This study refers to the irrigated cropland across Central Asia. Geographically, the whole area of Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan was included. From Kazakhstan, only the regions Almaty, Zhambul, South Kazakhstan, and Qyzylorda were included, because the regions further north and west do not have substantial cropland areas equipped with irrigation systems. Within this geographical region, only croplands in plains or valleys were included, while croplands on sloping lands (slope > 5°) were excluded, as such cropland usually is not equipped with irrigation systems. Xinjiang and Mongolia, which culturally and from the climate and ecological point of view belong to Central Asia, were not included in this study.

2.1. Mapping of Cropland under Irrigated Irrigation and Calculating the Length of Potential Tree Windbreaks

As a first step, the cropland, which was presumably under irrigated agriculture, was digitized manually from Landsat OLI satellite images from the growing season 2019. Afterwards, these cropland areas, broken down by countries and provinces, were intersected with line shape files, which resembled square shaped grids with grid cells of 1000 m × 1000 m, 500 m × 500 m, and 200 m × 200 m, respectively. Later, these different grids are referred to as the 1000 m grid, 500 m grid, and 200 m grid. The digitizing work was performed in Q-GIS (version 3.4, https://www.qgis.org/en/site/forusers/visualchangelog34/index.html, accessed on 24 May 2022), while the intersections and calculation of the line lengths were carried out in GRASS GIS (version 7.8, https://grass.osgeo.org/news/2019_09_15_grass_gis_7_8_0_released/, accessed on 24 May 2022).

From each Landsat tile, the cropland was digitized in spring (May–June) and summer (Aug to Sep), in order to accommodate for winter wheat and barley, which are harvested in June, and other crops, such as maize, cotton, and rice, which are harvested during late summer and autumn. The normalized vegetation index (NDVI) was calculated for each Landsat image, in order to separate cropland, which was cropped during 2019, from the cropland, which was left fallow at least during 2019. The NDVI was calculated as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

NDVI—normalized vegetation index; *NIR*—near infrared (channel 5 of Landsat OLI); *RED*—visible red (channel 4 of Landsat OLI)

The cropland, where the maximum NDVI was 0.2 and larger during 2019, was considered active cropland, which had been planted in 2019, while the remaining cropland was assumed to be fallow during 2019 (inactive cropland), as shown in an example in Figure 1.

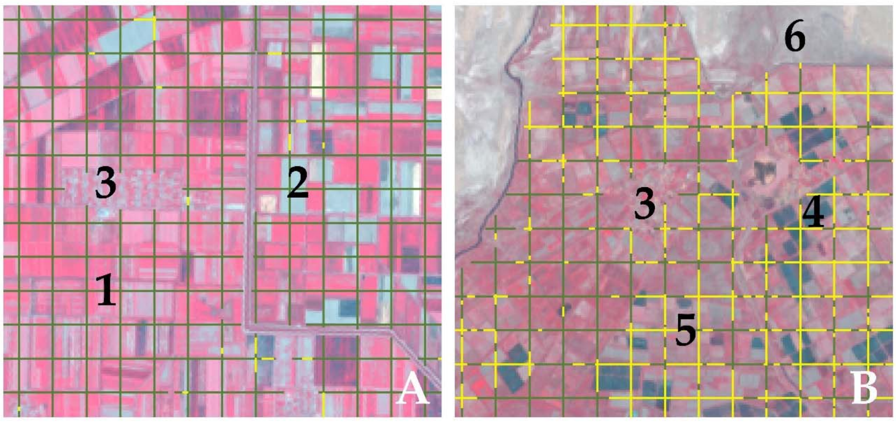

Figure 1. Example for line shapes that simulate tree windbreaks with 500 m spacing with Landsat OLI. Green: lines that intersect active cropland. Yellow: lines that intersect inactive cropland. 1: cropland that was cropped in 2019 with crops that are harvested in autumn (such as maize or cotton), 2: cropland that was cropped in 2019 with crops that are harvested in early summer (such as winter wheat), 3: settlement, 4: flooded paddy rice, 5: cropland rhat was not cropped in 2019 or not well managed so that the NDVI never reached 0.2, 6: desert. Panel (**A**): example from Tashkent Province, Uzbekistan; Landsat OLI from 20 August 2019. Panel (**B**): example from Karakalpakstan, Uzbekistan; Landsat OLI from 4 July 2019.

The potential tree windbreaks were simulated as line shapes with lines in the north–south and east–west direction, 1000 m, 500 m, or 200 m apart from each other, respectively. These line shapes were intersected with the active and the inactive cropland areas. Thus, the lines were cut back so that only those lines within respective cropland areas remained. Those lines resembled tree windbreaks under the assumption that each patch of cropland under irrigated agriculture across Central Asia was planted with tree windbreaks (Figure 1). Finally, the total lengths of those lines were calculated and aggregated by active versus inactive cropland and by province.

2.2. Calculation of Tree Numbers and Wood Volumes

Previous studies on tree windbreaks found that single tree rows of poplars, mainly the local *P. nigra* cultivar Mirza Terek, with an average of 116 trees per 100 m, had become the most common across the study region [17,23]. This study adopted that type of tree windbreaks and accordingly the tree density of 116 trees per 100 m was used to calculate the number of trees from the lengths of tree windbreaks. The number of trees was multiplied by the average timber and wood volume per tree to calculate the total volumes of all tree windbreaks, as is explained below.

In local markets, trees with a diameter at breast height (DBH) between 22 cm and 27 cm form the most common trading class [23]. Therefore, trees of that DBH range were used for further timber and wood volume calculations. Obviously, depending on the local climate, trees need longer or shorter time periods to attain that DBH class, which results in different rotation times.

The main difference in the local climates is the length of the growing season and winter and summer temperatures. As this study focusses on tree windbreaks in irrigated agriculture, no differences in water supply from precipitation were assumed, but sufficient water supply from irrigation. The length of the growing season was defined as the number of months with an average monthly air temperature of at least 5 °C (Table 1). The monthly average air temperatures were collected from [25].

The tree data set in the Supplementary Materials (Table S1), which contains tree data of 728 poplar trees (mainly the *Populus nigra* cultivar Mirza Terek) from tree windbreaks across the Ferghana Valley (Jalalabad Province), Chui Valley, and Issy Kul Province from the years 2016 to 2018, delivered the data to calculate the volumes of timber and other wood, as well as the rotation time for the potential tree windbreaks on the cropland across Central Asia's irrigated agriculture.

That data set contains DBH, tree height, stem volume, timber volume, other wood volumes, and tree age data. Tree height and DBH were measured in the field. Tree ages were determined from tree cores and farmers' statements. A subset of 31 trees was cut down to determine the form factor and the stem and wood volume. The stem volume was determined as the sum of the partial volumes of 1 m long stem sections. That stem volume served as the input to calculate the form factor, which is the ratio of the stem volume divided by the volume of a cylinder of the DBH and the tree height (Equation (2)). The average of those individual form factors (f = 0.421) was used to calculate the stem volume of all other trees on the data set (Table S1).

$$f = \frac{V}{\left(\frac{DBH}{2}\right)^2 \pi\, h} \tag{2}$$

f—form factor; V—stem volume (measured); DBH—diameter at breast height; h—tree height.

Table 1. Growing season, expressed as number of months with an average air temperature of ≥5 °C, and monthly average air temperature of January and July.

Country/Province	Growing Season	Length of Growing Season	Monthly Average Temperature [°C]	
		(Months)	January	July
Kazakhstan				
Almaty	April–October	7	−6	18.9
Qyzylorda	March–October	8	−5.7	28.5
South Kazakhstan	March–November	9	−0.8	26.9
Zhambul	March–October	8	−3.3	26
Kyrgyzstan				
Batken	March–November	9	0.1	24.4
Bishkek	April–October	7	−3.9	22.8
Chui	April-October	7	−3.9	22.8
Jalalabad	March–November	9	−2	24.6
Naryn	May–September	5	−14.8	13.3
Osh City	March–October	8	−4	22.4
Osh	March–October	8	−4	22.4
Talas	April–October	7	−7.4	19.8
Issyk Kul	May–September	5	−10.8	14.3
Tajikistan				
Dushanbe	March–November	9	−1.5	25.1
Gorno-Badakhshan	June–September	4	−16.7	12.4
Khatlon	February–December	11	4.3	32.4
Khujand	March–November	9	2.1	27.4
Tajikistan Territories	March–November	9	−1.5	25.1
Turkmenistan				
Ashgabat	March–November	9	3.2	30.2
Ahal	March–November	9	3.2	30.2
Balkan	February–November	10	3.4	32.3
Turkmenabad	March–October	8	2.4	33.1
Mary	February–December	11	4.6	31.9
Dashagouz	March–October	8	−1.6	30.1
Uzbekistan				
Andijan	March–November	9	0.2	29.1
Bukhara	February–November	10	2.6	31.6
Ferghana	March–November	9	1.7	29
Jizzak	March–November	9	1.3	27.4
Karakalpakstan	March–October	8	−2.7	29.4
Kashkadarya	February–November	10	3.4	29.8
Khorezm	March–November	9	−1.4	30.2
Namangan	March–November	9	0.7	30.1
Navoi	March–November	9	2.3	29.4
Samarkand	March–November	9	1.1	26.4
Syrdarya	March–November	9	2.6	30
Surkhandarya	February–December	11	4.8	33.6
Tashkent City	March–November	9	0.3	27.9
Tashkent	March–November	9	0.3	27.9

The stem and all branches of the trees that had been felled were separated into fractions of >5 cm diameter, 2–5 cm diameter, and <2 cm diameter and weighed to record the field fresh weight. A subsample of each fraction was oven-dried to determine the oven dry weight, its conversion factor from the field fresh weight to oven-dry weight, and to measure the wood density. All field fresh weights were converted into oven-dry weights and divided by the wood density, which yielded the volumes of each fraction. The bark thickness was measured at the DBH height, which allowed us to calculate the diameter of the stem wood at the DBH height and consequently the wood volume of the stem. The timber volume in this study refers to the stem volume without bark of the stem section that is thicker than

5 cm. According to farmers' information, that fraction of the stems was actually used in house construction and to manufacture furniture or household items. The branches and the remaining stem were used as fuel wood. Accordingly, those fractions of the felled trees were considered as other wood. The average ratio between timber volume and the volume of other wood was used to calculate the volume of other wood for all other trees on the data set.

Finally, all trees that fell into the DBH range of 22 cm to 27 cm, i.e., the size at which trees are cut and traded, were extracted from that tree data set (Table S1) and separated by their origin from Jalalabad, Chui, and Issyk Kul Province, respectively, to calculate the average DBH, tree height, stem volume, timber volume, other wood volume, and average tree age by province. The average volumes of timber and other wood of those three tree groups divided by the respective average tree age yielded the annual timber and wood increment by Jalalabad, Chui, and Issyk Kul Province, respectively. This annual increment summed up over all tree wind breaks of each of the provinces was taken as the maximum amount of timber and wood that can be harvested. The trees from those three provinces grow under different climatic conditions, as the length of the growing season is nine months in Jalalabad, seven months in Chui, and five months in Issyk Kul Province (Table 1). Finally, these data from Jalalabad, Chui, and Issyk Kul Province were used to calculate the volumes and annual increments of timber and other wood of all other provinces of the study region. Thereby, the data of Jalalabad, Chui, and Issyk Kul Province were assigned to the other provinces with a growing season of ≥9 months, 7–8 months, and ≤6 months, respectively (Table 1).

The results from the timber and wood volume calculations as described above delivered a theoretical upper limit of the amount of wood resources that can be accrued from tree windbreaks, because not all cropland will be planted with tree windbreaks. Ruppert et al. [22] found that on average, 26% of farmers had a positive perception of tree windbreaks across different regions of Kyrgyzstan. For a more realistic assessment of the timber and wood volumes that can be delivered by tree windbreaks, the theoretical maxima of tree windbreak length, number of trees, timber volume, and wood volume were multiplied by 0.26 to obtain the corresponding numbers, which is named "current adoption" herein after in this study. The assumption behind "current adoption" was that according to the current farmers' perception, 26% of the potential tree windbreaks actually would become tree windbreaks. Countries' policies or an increasing demand for domestically produced wood have the potential to increase the number of farmers who eventually plant tree windbreaks so that another set of tree windbreak length, number of trees, timber volume, and wood volume was calculated, under the assumption that 50% of the potential tree windbreaks would be realized, which is named "optimistic adoption" further on in this study.

3. Results

3.1. Tree Data

For this study, trees with DBH between 22 cm and 27 cm were chosen for further volume calculations. Trees within this DBH range, but from different growing season lengths, are introduced in Table 2 with regard to their tree height, DBH, tree age, as well as stem, timber, wood volume. The figures of the timber volume (wood volume of stem parts with diameter >5 cm), other wood, and tree age were used to calculate the potential annual timber and other wood harvests (cf. Section 3.4).

3.2. Cropland Area of Irrigated Agriculture

The cropland area of irrigated agriculture was largest in Uzbekistan with 5.4 million ha, followed by Turkmenistan with 2.7 million ha, Kazakhstan with 2.6 million ha, Kyrgyzstan with 1 million ha, and Tajikistan with 0.75 million ha (Table 3).

Table 2. Tree data (average ± standard deviation) from the three groups of different lengths of growing season. Thereby, the initial tree data for the length of growing season of ≥9 months, 7–8 months, and ≤6 months came from the trees with a DBH of 22 cm to 27 cm from Jalalabad, Chui, and Issyk Kul Province, respectively.

Length of Growing Season in Months	≥9	7–8	≤6
Tree age [yr]	13 ± 4	17 ± 1	27 ± 11
Tree height [m]	20.2 ± 2.8	16 ± 1.4	17 ± 3.2
DBH [cm]	24.6 ± 1.7	24.5 ± 1.5	24.6 ± 1.5
Stem volume (m^3)	0.407 ± 0.077	0.309 ± 0.054	0.341 ± 0.071
Stem volume without bark (m^3)	0.371 ± 0.070	0.281 ± 0.049	0.310 ± 0.065
Timber volume (wood volume of stem parts with diameter > 5 cm) (m^3)	0.361 ± 0.068	0.274 ± 0.048	0.302 ± 0.063
Other wood volume (branches, twigs, stem with diameter ≤ 5 cm) (m^3)	0.121 ± 0.023	0.092 ± 0.016	0.101 ± 0.021

Table 3. Cropland area under irrigated agriculture by country and province.

Country/Province	Active Cropland [ha]	Inactive Cropland [ha]	Total Cropland [ha]
Kazakhstan			
Almaty	167,241	80,942	248,183
Qyzylorda	1,012,924	104,630	1,117,554
South Kazakhstan	211,172	64,313	275,485
Zhambul	797,161	128,228	925,389
Total Kazakhstan	2,188,498	378,113	2,566,611
Kyrgyzstan			
Batken	48,694	3483	52,177
Bishkek	2129	49	2178
Chui	395,833	22,521	418,354
Jalalabad	129,667	61	129,728
Naryn	31,617	38	31,655
Osh City	303	25	328
Osh	73,710	4037	77,747
Talas	90,023	40,201	130,225
Issyk Kul	124,506	34,931	159,437
Total Kyrgyzstan	896,482	105,347	1,001,829
Tajikistan			
Dushanbe	2549	65	2614
Gorno-Badakhshan	3775	283	4059
Khatlon	343,357	22,973	366,330
Khujand	283,862	23,336	307,198
Tajikistan Territories	72,705	1261	73,965
Total Tajikistan	706,247	47,919	754,166
Turkmenistan			
Ashgabat	434	151	585
Ahal	545,671	508,375	1,054,046
Balkan	48,202	164,351	212,553
Turkmenabad	208,591	95,705	304,296
Mary	340,595	159,618	500,213
Dashagouz	384,573	330,325	714,898
Total Turkmenistan	1,528,066	1,258,526	2,786,592
Uzbekistan			
Andijan	256,109	11,143	267,252
Bukhara	303,816	43,763	347,579
Ferghana	344,587	26,879	371,465
Jizzak	612,151	49,880	662,032
Karakalpakstan	446,676	210,703	657,379
Kashkadarya	460,619	216,931	677,550

Table 3. *Cont.*

Country/Province	Active Cropland [ha]	Inactive Cropland [ha]	Total Cropland [ha]
Khorezm	301,307	32,299	333,606
Namangan	286,758	20,930	307,688
Navoi	181,488	19,156	200,644
Samarkand	414,774	109,785	524,559
Syrdarya	340,618	24,658	365,275
Surkhandarya	266,098	31,820	297,919
Tashkent City	3123	257	3380
Tashkent	388,728	8341	397,069
Total Uzbekistan	4,606,853	806,544	5,413,397

With respect to the active cropland area, which was the cropland, where the NDVI peaked with at least $\geq$0.2 during the growing season 2019, the countries ranked the same. Only Turkmenistan had much less active cropland, 1.5 million ha, than Kazakhstan with 2.2 million ha (Table 3). Regions further downstream along the rivers had larger shares of inactive cropland compared to regions further upstream. As a whole country, inactive cropland covered 45% of the total cropland area in Turkmenistan, and in Uzbekistan, for the regions Karakalpakstan and Kashkadarya, the inactive cropland accounted for 32% of the total cropland each. In contrast, the Tashkent region in Uzbekistan only had a share of 2% inactive cropland and Kyrgyzstan as a whole country only 11%.

3.3. Length of Potential Tree Windbreaks and Number of Trees

The potential length of tree windbreaks, if planted across all active cropland under irrigated agriculture in Central Asia, so the theoretical maximum, amounted to 199,000 km, 398,000 km, and 994,000 km under a 1000 m grid, 500 m grid, and 200 m grid, respectively (Table S2). These numbers would increase to 251,000 km, 502,000 km, and 1,254,000 km, respectively, if the inactive cropland was added to the active cropland (Table S2). These potential tree windbreak lengths corresponded to 231 million, 461 million, and 1153 million trees across all active cropland under irrigated agriculture in Central Asia under a 1000 m grid, 500 m grid, and 200 m grid, respectively. The number of trees would increase to 291 million, 582 million, and 1455 million trees, respectively, if the potential of the inactive cropland was added (Table S2). The numbers of this theoretical maximum are listed in Supplementary Table S2 by country and province.

The tree windbreak lengths under current adoption, which is 26% of the theoretical maximum, are listed in Table 4 by country and the different grid sizes. By country, Uzbekistan harbored almost half of Central Asia's potential length of tree windbreaks on active cropland, followed by Kazakhstan, Turkmenistan, Kyrgyzstan, and Tajikistan. This ranking corresponds to the cropland area of those countries. Corresponding to the tree windbreak lengths, Uzbekistan harbored almost half of all those trees of Central Asia's potential tree windbreaks on active cropland. Under the current adoption, there were (rounded to thousands) 52,000 km, 103,000 km, and 120,000 km of tree windbreaks across the active cropland under a 1000 m grid, 500 m grid, and 200 m grid, respectively (Table 4). The tree windbreak lengths and corresponding tree numbers by country and province are listed in the Supplementary Table S3 for current adoption and Table S4 for the optimistic adoption.

3.4. Timber and Wood Volume from Tree Windbreaks

The theoretical maximum of the timber volume of tree windbreaks, if planted across all active cropland under irrigated agriculture in Central Asia in a 1000 m grid, 500 m grid, and 200 m grid, summed up to 73.8 million m^3, 156.2 million m^3, and 390 million m^3, respectively (Table S2). Those numbers shrunk to 19.1 million m^3, 40.6 million m^3, and 101 million m^3, respectively, under calculations of current adoption (Table 5).

Table 4. Length of tree windbreaks by country under assumption of 1000 m, 500 m, and 200 m grids, current adoption (26% of the potential tree windbreaks realized).

Country	Potential Length of Tree Windbreaks (1000 km) on:		
	Active Cropland	Inactive Cropland	Total Cropland
1000 m grid			
Kazakhstan	11.4	2.0	13.4
Kyrgyzstan	4.7	0.6	5.2
Tajikistan	3.7	0.2	3.9
Turkmenistan	7.9	6.6	14.5
Uzbekistan	24.0	4.2	28.2
Total Central Asia	51.7	13.5	65.2
500 m grid			
Kazakhstan	22.8	3.9	26.7
Kyrgyzstan	9.3	1.1	10.4
Tajikistan	7.4	0.5	7.9
Turkmenistan	15.9	13.1	29.0
Uzbekistan	48.0	8.4	56.4
Total Central Asia	103.4	27.0	130.4
200 m			
Kazakhstan	56.9	9.8	66.8
Kyrgyzstan	23.3	2.7	26.1
Tajikistan	18.4	1.2	19.6
Turkmenistan	39.8	32.8	72.5
Uzbekistan	120.0	21.0	141.0
Total Central Asia	258.4	67.6	326.0

Table 5. Timber volume (standing) under 1000 m, 500 m, 200 m grids by country (million m^3), current adoption (26% of the potential tree windbreaks realized).

Country	Timber Volume (Standing) (Million m^3) on:		
	Active Cropland	Inactive Cropland	Total Cropland
1000 m grid			
Kazakhstan	4.2	0.7	4.9
Kyrgyzstan	0.5	0.1	0.6
Tajikistan	1.5	0.1	1.6
Turkmenistan	3	2.5	5.6
Uzbekistan	9.9	1.7	11.5
Total Central Asia	19.1	5.1	24.3
500 m grid			
Kazakhstan	8.5	1.4	9.9
Kyrgyzstan	3.2	0.4	3.6
Tajikistan	3.1	0.2	3.3
Turkmenistan	6.1	5.1	11.2
Uzbekistan	19.7	3.3	23
Total Central Asia	40.6	10.3	50.9
200 m			
Kazakhstan	21.1	3.5	24.6
Kyrgyzstan	8.2	0.9	9.1
Tajikistan	7.7	0.5	8.2
Turkmenistan	15.3	12.7	28
Uzbekistan	49.2	8.3	57.5
Total Central Asia	101	26	127

The theoretical maximum of annual timber harvest from tree windbreaks with a harvesting rate of 100% of the total harvestable volume in m^3 across the active cropland was 5.6, 11.3, and 28.1 million m^3 per year for Central Asia as a whole, if we look at 1000 m, 500 m, and 200 m tree windbreak grids, respectively (Table S2). In this table, the numbers divided by countries and provinces are also listed. The calculations for an optimistic adoption resulted in annual timber volumes of half the numbers above (Table S4), while the current adoption (adoption rate of 26%) resulted in 1.5, 2.9, and 7.3 million m^3 per year, respectively (Tables 6 and S3).

Table 6. Timber volume per year, volume of other wood per year, and total wood volume per year under 1000 m, 500 m, 200 m grids by country (million m^3), current adoption (26% of the potential tree windbreaks realized).

Country	Timber Volume per Year ($1000\ m^3\ yr^{-1}$)		Volume of Other Wood per Year ($1000\ m^3\ yr^{-1}$)		Total Volume per Year ($1000\ m^3\ yr^{-1}$)	
	Active Cropland	Total Cropland	Active Cropland	Total Cropland	Active Cropland	Total Cropland
1000 m grid						
Kazakhstan	289	334	20	23	309	357
Kyrgyzstan	97	107	6	7	103	114
Tajikistan	118	126	9	10	127	135
Turkmenistan	216	399	16	29	232	428
Uzbekistan	745	866	56	65	801	931
Total Central Asia	1465	1831	107	133	1572	1965
500 m grid						
Kazakhstan	578	668	40	46	618	714
Kyrgyzstan	195	214	12	13	207	227
Tajikistan	236	252	18	19	254	272
Turkmenistan	433	798	31	58	465	856
Uzbekistan	1486	1728	113	131	1599	1859
Total Central Asia	2928	3661	214	267	3142	3927
200 m grid						
Kazakhstan	1442	1668	100	115	1542	1783
Kyrgyzstan	486	534	30	33	516	567
Tajikistan	590	630	45	48	636	679
Turkmenistan	1083	1996	78	144	1161	2140
Uzbekistan	3716	4322	282	326	3998	4649
Total Central Asia	7317	9151	535	667	7853	9818

Among the provinces, the smallest annual timber amounts were calculated for the mountainous provinces Gorno-Badakhshan in Tajikistan and Naryn in Kyrgyzstan, where the cropland area is small and which have the shortest growing seasons. Evidently, cities were also among the administrative units with the smallest annual timber amounts.

The annual volume of other wood, i.e., branches, twigs, and stem parts smaller than 5 cm in diameter (current adoption), from the active cropland across Central Asia was 0.1, 0.2, and 0.5 million m^3 per year for a 1000 m, 500 m, and 200 m grid, respectively (Tables 6 and S3).

4. Discussion

The tree data that were used in this study (Table 2) are in the same range as the tree data of poplars in other agroforestry systems. A study in India [26] reported timber volumes of poplars with a DBH of 24 cm. The timber volumes were 0.341 m^3 and 0.415 m^3, of trees with heights of 18 m and 22 m, respectively. Timber volumes without bark were 0.282 m^3 and 0.313 m^3 for trees of 18 m and 20 m height, respectively. The data published by Rizvi et al. [27], also from India, report that poplar trees in agroforestry systems with a DBH of 21.70–27.45 cm and tree heights of 20.13–24.30 m have timber volumes of 0.224–0.353 m^3. Those volumes are in the same range as the data that were used in this study. Seventeen-year-old *P.* × *canadensis* trees in a plantation in Jiangsu, China [28], reached a DBH of 24.2 cm to 27.2 cm, with tree heights of 21.3 m to 22.4 m. This corresponds to trees from areas with a growing season of 9 months and longer, which matches with the growing season in Jiangsu. A DBH of 24.6 cm corresponded with a stem volume of 0.47 m^3, which is larger than the trees of this study. This difference might be explained by differences between the poplar species *P. nigra*, which was the dominant one in this study, and *P.* × *canadensis*.

The cropland area, as was digitized for this study, is similar to data on irrigated cropland by FAOSTAT [18] (Tables 3 and 7). For Kyrgyzstan, the numbers of digitized cropland and reported cropland are very close. For Kazakhstan, the area of active cropland, as digitized for this study, matches with the area equipped with irrigation as reported by FAOSTAT [18], while the total digitized area is much larger. This difference can be partly explained by inactive cropland areas in the Almaty and Zhambul provinces, which met the criteria for the digitizing and selection afterwards, but today are no longer equipped with irrigation systems, and therefore have not been reported to FAO. The same applies to Uzbekistan, where cropland that had been irrigated during the Soviet Union period was abandoned after independence, due to salinization and dropping water supply from the Amu Darya River. It is possible that those areas are no longer reported to FAOSTAT.

Table 7. Cropland under irrigated agriculture as digitized within this study and irrigated cropland according to [18].

Country	Active Cropland [1000 ha] as Digitized	Total Cropland [1000 ha] as Digitized	Cropland Equipped with Irrigation [18] [1000 ha]	Cropland Actually Irrigated [18] [1000 ha]
Kazakhstan	2188	2567	2204	1779
Kyrgyzstan	896	1002	1023	934
Tajikistan	706	754	822	747
Turkmenistan	1528	2787	1995	
Uzbekistan	4607	5413	4306	

For Uzbekistan, the annual timber harvest from a 1000 m tree windbreak grid under the calculations for current adoption was slightly more than twice the current annual roundwood production and imports of the country, as published by FAOSTAT [18] in Table 8. In Kyrgyzstan, the tree windbreaks with 1000 m spacing would provide the same amount of timber volume as the current domestic production and imports together. In Kazakhstan, the annual timber harvest from a 500 m tree windbreak grid met the current roundwood production of the country [18]. Therefore, in those three countries, tree windbreaks already at the wider spacings of 1000 m and 500 m, respectively, and under the current adoption can deliver wood resources domestically as a raw material for wood-based value chains, ranging from construction material for housing to applications from the field of bioeconomy, such as the production of cellulose, fiber, and other chemicals, while reducing pressure on forests for domestic timber production and potentially reducing the need for timber and wood imports. Tree windbreaks with spacing of 500 m (current adoption) would provide about twice the current roundwood production and import of Kyrgyzstan and about 4.5-times the current roundwood production and import of Uzbekistan. Such substantial contributions can be expected for Tajikistan and Turkmenistan as well. Evidently, a higher adoption rate and, even on parts of the cropland, establishment of tree windbreaks with 200 m spacing would result in higher amounts of domestic wood production. Further potential to increase the annually available timber and wood volume lies in introducing poplar cultivars, which have been developed more recently compared to the currently dominant cultivar Mirza Terek. In particular, *P. deltoides* × *nigra* and *P. nigra* × *maximoviczii* cultivars were shown to have a substantially higher growth potential than Mirza Terek [29]. This high potential of agroforestry systems to deliver domestic timber and other wood resonates with the outcomes of agroforestry adoption in India. There, an estimated 65% of the country's timber and almost half of its fuel wood come from trees grown on farms [30,31].

While the assessment of agroforestry potential above was based on the locally dominant cultivar Mirza Terek, a *P. nigra* cultivar, to keep the calculations simple, there are good reasons to argue for more diversity in the tree species used. On the one hand, using the same species, or possibly the same clone or variety, makes the agroforestry system vulnerable to calamities or the impacts of climate change. From an ecological point of view, using locally adapted cultivars of poplar and other tree species should be favored. Even if the growth rate might be lower than with poplars as the only tree species, the value of the timber, for example for different construction purposes, can be higher. Such assessments can be built on the findings of this paper to advance the understanding for scientists and practitioners.

Table 8. Annual production, import, and export of roundwood and annual fuel wood production, all in 1000 m^3, for the five countries of Central Asia [17].

Country	Year	Roundwood, Production	Roundwood, Import	Roundwood, Export	Fuel Wood, Production
Kazakhstan	2015	340	137	0	241
	2020	496	138	19.3	303
Kyrgyzstan	2015	45.9	5.2	0	36.6
	2020	45.9	40.1	15.2	36.6
Tajikistan	2015	3600	15.9	0	3600
	2020	3674	2.9	0.16	3674
Turkmenistan	2015	0	13	0	0
	2020	10	38.4	0	10
Uzbekistan	2015	34	283	0.55	24
	2020	23.7	295	0.13	17.7

5. Conclusions

This study assessed the potential absolute and annually available poplar timber and wood volumes delivered by tree windbreak systems on irrigated cropland across Central Asia. Under the assumptions of an adoption rate of these tree windbreak systems of 26% of the geographically and theoretically possible expansion, tree windbreak systems deliver wood resources that exceed the levels of current production and imports. Therefore, tree windbreaks offer great untapped potential to deliver wood resources domestically as a raw material for wood-based value chains (e.g., construction material for housing), but also for further value chains in the field of bioeconomy, such as the production of cellulose, fiber, and other chemicals. Next to wood as a raw material, tree windbreaks deliver co-benefits, such as improving the local climate, which favors crop production. Research is needed to further assess farmers' perceptions and willingness to plant and manage shelterbelts, as well as analyzing the current processing capacities in the timber-based value chains. In addition, future climate conditions may pose a challenge to the agroforestry systems, despite their water saving capacity. From an ecological point of view, the use of a single tree species can pose risks; thus, studies on the potential of other locally adapted species are needed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13081193/s1, Table S1: Poplar tree data from Ferghana Valley, Chui Valley, and Issyk Kul. Table S2: Tree wind break length, number of trees, timber and wood volumes, theoretical maximum; 100% of all potential tree wind breaks are realized. Table S3: Tree wind break length, number of trees, timber and wood volumes under current adoption; 26% of all potential tree wind breaks are realized. Table S4: Tree wind break length, number of trees, timber and wood volumes, theoretical maximum; 50% of all potential tree wind breaks are realized.

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