Forest Landscape Restoration and Sustainable Biomass Utilization in Central Asia

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1. Introduction

Land use and land degradation are cross cutting issues related to and impacted by many SDGs, like SDG 1 (no poverty), SDG 2 (ending hunger), SDG 8 (decent work and economic growth), SDG 12 (responsible consumption and production), SDG 13 (climate action), and in particular SDG 15 (life on land) with all its targets. SDG 15 is to protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (UN 2015).

Forest landscape restoration (FLR) has been developed as an approach to restore forests and whole landscapes that interact with forests (Maginnis and Jackson 2005; Mansourian et al. 2005). In the meantime, FLR has become an approach that addresses a wide range of landscapes beyond forests as woodlands and includes restoration approaches like agroforestry (Stanturf et al. 2019). Despite its wide range, Veldman (2015) argues that trees must not dominate restoration approaches, e.g., in grassy landscapes that never had trees.

Under the Bonn Challenge, FLR has gained global attention in forest rich as well as forest poor countries, like the countries in Central Asia. Globally, countries have committed themselves to implement FLR on 350 million ha by 2030 (Bonn Challenge 2021).

FLR, as other restoration efforts, needs to yield income for the people who engage in this and who are affected, in particular for rural communities in poor countries (Stanturf et al. 2019). This is often a challenge, but could be an option as well, as trees do yield biomass, which is a raw material for bioeconomy.

Bioeconomy, if seen solely as the production of renewable biological resources as basis for food, feed, bio-based products, and bio-energy, will not meet the targets of SDG 15 (Heimann 2019). Heimann (2019) analyzed the effects of bioeconomy and so-called sustainable bioeconomy on SDG 15 and found that only sustainable bioeconomy will help in fulfilling SDG 15, while bioeconomy will negatively impact SDG 15. Bioeconomy may allow one to clear forests or other natural ecosystems in favor of intensive biomass production, which is in contradiction to SDG 15.2, which calls for the restoration and protection of forests, and to SDG 15.5, which calls to halt loss of biodiversity and reduce the degradation of natural habitats. Sustainable bioeconomy according to the Global Bioeconomy Summit (2015) optimizes the production and utilization of biological resources, while ensuring food security and protecting ecosystems.

Martinez de Arano et al. (2018) compiled the potentials of ligno-cellulose biomass from forests in southern Europe as feed stock for a wide range of bioeconomy value chains, which does not compete with food production. The applications for that biomass listed there range from bioenergy over textiles (viscose), sugars as chemical building blocks, and lignin, to produce carbon fibers to engineered wood products and house construction.

Central Asia is a region that, after a period of severe land degradation, has recently joined the Bonn Challenge, visible by the Astana Resolution from 2018 (Bonn Challenge 2018) and pledged a total of 2,389,000 ha by today (Bonn Challenge 2021). Like other regions of the world, Central Asia also faces the need to allocate resources to FLR and to generate income in line with FLR to fulfill these pledges. This is a burden and an opportunity at the same time, because this region has space to offer the FLR as well as the bioeconomy. On the other side, Central Asia harbors a large share of the world's winter-cold deserts and is the region with the highest number of closed river basins worldwide. The most well-known of those river basins is the Aral Sea Basin due to the desiccation of that lake. This semi-arid to arid climate adds another obstacle against FLR. Against this background, this chapter will introduce the needs for restoration and protection of landscapes, of FLR and beyond, and introduce examples for biomass utilization as bioeconomy feedstocks that help restore landscapes. These approaches from a vast dryland region as Central Asia may inspire FLR in other dryland regions of the world.

2. Land Degradation across Central Asia

2.1. Central Asia—Geography, Climate, Landscapes

Central Asia, roughly speaking, refers to the land mass stretching from the Caspian Sea in the west into Northwest China and Mongolia in the east, between Siberia in the north and Afghanistan in the south. The boundaries of this region differ from author to author, but all sources include the five countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, which share a common history of the Soviet Union, in Central Asia. This chapter, therefore, will refer to those five countries (Figure 1).

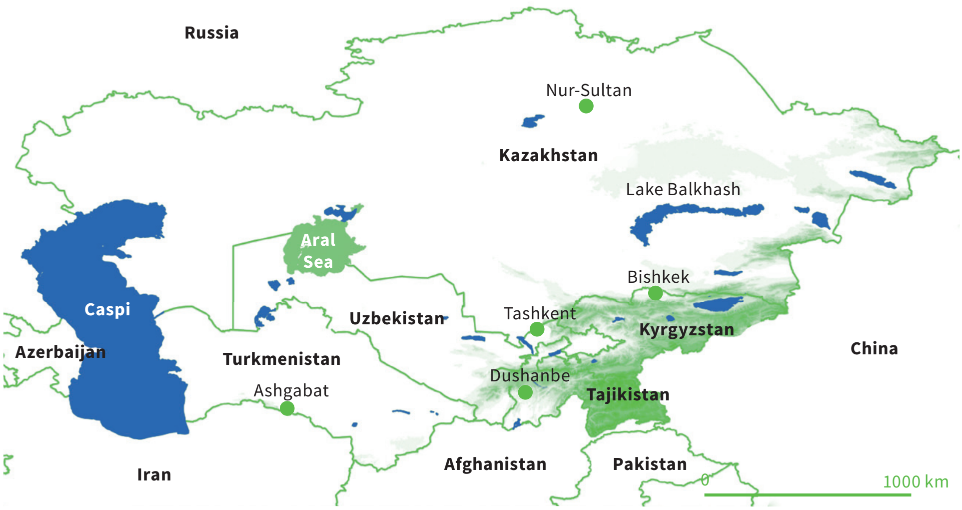

Figure 1. Map of the five Central Asian countries with major waters and elevation. Source: Figure by author.

In terms of area, Central Asia is largely dominated by plains and undulating steppe and desert landscapes on an elevation of below 1000 m above sea level (a.s.l.), which cover most of Kazakhstan, Turkmenistan, and Uzbekistan. The southeastern part of that region is dominated by mountains, the Tianshan and Pamirs in Kyrgyzstan and Tajikistan. Very small parts of those mountain ranges are located in Kazakhstan and Uzbekistan. In addition, Kazakhstan shares the Altay Mountains with Russia, Mongolia, and China (ADB 2010).

The climate throughout the region is continental, with cold to very cold winters and warm to hot summers. Average January temperatures are as low as −16 °C in Nur-Sultan, Kazakhstan's capital, −2.6 °C in Bishkek (Kyrgyzstan), 1.9 °C in Tashkent (Uzbekistan), and 4 °C in Tajikistan's capital, Dushanbe. Corresponding average July temperatures are 20 °C, 24.9 °C, 27.8 °C, and 27 °C in Nur-Sultan, Bishkek, Tashkent, and Dushanbe, respectively (Weatherbase 2020). Due to the location far away from any ocean, the climate is semi-arid to arid with an annual precipitation of, e.g., 140 mm in Balkhash at Lake Balkhash in Kazakhstan, 145 mm in Aralsk, close to the Aral Sea in Kazakhstan, and 130 mm in Turkmenabad (Turkmenistan). Precipitation increases in the forelands of the mountains, as illustrated by the annual precipitation of Bishkek, Tashkent, and Dushanbe with 452 mm, 440 mm, and 530 mm, respectively (Weatherbase 2020), and more so in the mountains, with places with annual precipitations of around 1000 mm, e.g., in the mountains northeast of the

Ferghana Valley (ADB 2010; Sakbaeva et al. 2013) and more than 1800 mm in Central Tajikistan (Djumaboev et al. 2020). The precipitation maximum falls in the months March, April, and May for most of the region, e.g., in Bishkek, 40% of the annual precipitation occurs in these three months.

The area outside the mountains is largely covered by zonal vegetation types, which are, from north to south, forest steppe, steppe, dry steppe/semi desert, and desert. The steppes are located in Kazakhstan, whereas Turkmenistan and Uzbekistan are largely covered by deserts. Thereby, it is noteworthy that the deserts of the region, being winter-cold deserts, harbor shrubby vegetation mainly from White Saxaul (*Haloxylon persicum*), *Artemisia* spec., and *Salsola* spec. Many plant species have adapted to use the soil moisture from snow melt and rain fall in spring and finish their annual life cycle in early summer when the soil moisture has been exploited. Woody species are psammophytes and survive the arid conditions in the desert by developing deep roots to exploit a large soil volume for water (Rachkovskaya et al. 2003).

In the mountains and their forelands, the vegetation zones along with increasing elevation are generally: submontane steppes, broad-leaf forests, Coniferous forests (montane forests), alpine shrubs and meadows, and rocks, snowfields, and glaciers. Forests are mainly distributed on northeast, north, and northwest exposed slopes, because other slopes are too dry for tree growth (Orozumbekov et al. 2009). Of course, the spatial pattern of these zones differs according to local climatic conditions, in particular the absence or presence of forests and their vegetation coverage and species composition. The plant species of the submontane steppe behave like the plants in the steppes with regard to water and finish their life cycle early in summer, while the tree species of the mountain forests need a rather continuous water supply over the whole year.

In Tianshan, the coniferous forest zone lies between 1700 m and 3200 m a.s.l. (Scheuber et al. 2000), with *Picea schrenkiana* being distributed from 1700 m to 2800 m a.s.l. and *Juniper* species up to 3200 m a.s.l. Broad leaf forests in Central Asia, except for the Altay and northern part of Kazakhstan, are walnut wild fruit forests or pistachio forests. The former consists of walnuts (*Juglans regia*) and wild fruit trees of the Rosaceae family, i.e., apple (*Malus kirghisorum* and *M. sieversii)*, pear, plum (*Prunus sogdiana*), cherry (*Prunus mahaleb*), peach, and apricot. In the mountains northeast of the Ferghana Valley, these forests form large areas on an elevation from 700 m to 1100 m a.s.l. (Scheuber et al. 2000; Beer et al. 2008). The largest parts of these forests are located in Kyrgyzstan, though small parts are also located in the Chatkal Mountain Range, which is the Uzbek part of the Tianshan northeast of Tashkent. Such walnut wild fruit forests also occur in the Pamirs in Tajikistan, though on higher elevations compared to Tianshan. Pistachio is distributed in lower elevations, below the walnut wild fruit forests (USAID 2001a). In northern Kazakhstan, Aspen and Birch form small forests in a mosaic with steppes in the forest-steppe zone (USAID 2001b).

In the mountains, the precipitation feeds numerous rivers, either directly from rain fall or through snow and glacier melt water. All those rivers, except for the Irtysh River in Kazakhstan, drain into endorheic river basins, i.e., these rivers do not reach the open sea, but end in an end-lake, an inland delta, or simply vanish in one of the deserts. The Amu Darya and Syr Darya are the largest rivers of the region and drain into the Aral Sea (ADB 2010; Djumaboev et al. 2020). The Ili River, with its headwaters in China, drains into Lake Balkhash in Kazakhstan, which today has become the largest lake of Central Asia after the Aral Sea has been desiccating and shrinking (Imentai et al. 2015). The Chui River and Talas River, both shared between Kyrgyzstan upstream and Kazakhstan downstream, each form an inland delta in the Muyinkum Desert in southern Kazakhstan (ADB 2010). Along those rivers, riparian forests and woodlands (Tugai forests) Willow species, *Populus pruinosa*, *Populus euphratica*, Russian Olive (*Elaeagnus angustifolia*), and Black Saxaul (*Haloxylon aphyllum*), as well as wetlands with Common Reed (*Phragmites australis*), form an azonal vegetation (Rachkovskaya et al. 2003). The plant species of the Tugai forests survive the arid climate by exploiting the groundwater (so-called phreatophytes) so that these plant species remain productive during the whole growing season. The wetland plant species depend on high groundwater levels or surface waters to survive. The Tugai forests and wetlands are the most productive natural vegetation types across the whole region of Central Asia (Thevs et al. 2012a). Despite its semi-arid to arid climate, wetlands are significant in that region, as Kazakhstan alone harbors about 2 million ha of reed beds out of 10 million ha globally, which makes it the country with the largest reed bed area (Köbbing et al. 2013) worldwide.

2.2. Land Degradation across Central Asia

Most of Central Asia's population concentrates along the rivers and in the river valleys because there is enough water available for irrigation in agriculture and other human water uses. Therefore, already early in history, Tugai forests and wetlands were reclaimed to give space to cropland and settlements. Though most of the land degradation, the results of which we see today, took place during the past 100 years, which is during Soviet Union times and after the independence of the Central Asian countries (UNECE/FAO 2019). Today, the degraded area ranges from

8% of the total land area for Turkmenistan and Uzbekistan to 60% across Kazakhstan (Mirzabaev et al. 2020).

Starting in the 1960s, huge areas in Central Asia were reclaimed for agriculture. Along the rivers, mainly along the Amu Darya and Syr Darya, irrigated agriculture was expanded for cotton production. After independence, land under irrigation in Uzbekistan and Turkmenistan was further enlarged as wheat production added to cotton to feed the countries' populations. Along the enlarged areas, water abstraction for irrigation increased, which resulted in the desiccation the Aral Sea and degradation of Tugai forests and wetlands. Large areas of irrigated cropland have been degraded by soil salinization.

In the steppe regions of Kazakhstan, from 1954 to 1970, a total of 20.9 million ha of steppe vegetation was converted into cropland, mainly for wheat production, which resulted in humus loss. Due to low yields, many of these areas were not competitive under the market economy after independence and fell fallow. From 1992 to 1998, 19.6 million ha of that cropland was abandoned (Lenk 2005). Today, such reclaimed areas in northern Kazakhstan are cultivated again (Kraemer et al. 2015).

During Soviet Union times, large areas of forests were cleared or degraded, e.g., forest cover in Tajikistan shrunk from 16–18% of the country's surface 100 years ago (USAID 2001c) to 2.9% today (FAO 2015), mainly due to conversion into cropland. In Turkmenistan, from the former Saxaul forest and woodland area less than one third remains today. In Uzbekistan, 81% of the Saxaul forests and woodlands disappeared (Thevs et al. 2013). Saxaul forests and woodlands were logged for fuel and overgrazed. Tugai forests were cleared as well, to give space to irrigated agriculture. The more irrigation took place and the more water was abstracted from rivers, the less water remained for Tugai forests, wetlands, and water bodies. The desiccation of the Aral Sea is the largest example of this cascade of degradation. From the first half of the 20th century until today, 90% of the former Tugai forests vanished in Uzbekistan (USAID 2001a).

During Soviet Union time, Central Asia imported timber and energy sources (coal, oil, gas, electricity) from the Russian SSR. With the independence of the five countries, these imports came to an abrupt end, which resulted in a surge of forest and other landscape degradation. As wood became the main energy source, in particular for rural communities, fuelwood removal was the major driver of forest degradation after independence. Later, during the 1990s, overgrazing and tree cutting for timber became drivers of forest degradation. Today, fuelwood demand does not impact forests in Kazakhstan and Turkmenistan, where gas supply has been substantially improved. In Kyrgyzstan, rural communities use more and more coal and electricity so that the share of fuelwood in the energy mix decreases. Tree cutting for timber and grazing still remain as drivers of forest degradation. Low river runoffs result in water stress for Tugai forests and wetlands and add to their degradation (UNECE/FAO 2019).

Today, 70% of the territory of Kazakhstan is considered degraded to varying extents (UNDP 2015a). Most of those degraded areas are deserts, steppes, and agricultural land and are affected by overgrazing and salinization.

3. Options for Forest Landscape Restoration and Biomass Utilization

3.1. The Need for Restoration and Income Generation and a Focus on Biomass Utilization

From the previous section, it has to be concluded that there is a need for restoration across all landscape and vegetation types of Central Asia, and non-degraded landscapes must be protected from degradation. First of all, landscapes along the rivers and river valleys have to be protected and restored, as most of the population in Central Asia concentrates along rivers and in river valleys. Following the river course from its headwaters downstream, alpine meadows and mountain forests have to be protected from further degradation and restored to firstly buffer rainfall and snowmelt in the mountains, which regulates the river runoff and dampens flood events and secondly combat soil erosion and landslides. Landslides pose a risk to communities. Ongoing soil erosion and landslides result in siltation of reservoirs and water infrastructure (Havenith et al. 2017).

Further downstream, where rivers flow through the steppes and deserts, productivity in agriculture has to be maintained, as this is the basis for a large share of livelihoods in the Central Asian countries. More than half of Central Asia's population is rural, and agriculture is the largest single employer in the countries (Table 1).

Tugai forests and wetlands need to be restored and protected as well, because they are the most productive ecosystems in the region and provide huge amounts of biomass that, currently, is mainly used as fodder—Tugai forests and wetlands are major pasture lands, in particular in the desert region—but offer more higher-value uses, as described in Section 3.3. Furthermore, these ecosystems are hotspots for biodiversity, as reflected in the list of Ramsar Sites of the Central Asian countries.

Table 1. Population (total and rural) and employment in agriculture in the Central Asian countries.

Country	Population in 2018 (FAO 2020)			Employment in Agriculture in 2016 [%] (World Bank 2020)	
	Total [Million]	Rural in [%]	Urban in [%]	Male	Female
Kazakhstan	18.3	43	57	19	17
Kyrgyzstan	6.3	62	38	28	32
Tajikistan	9.1	73	27	45	73
Turkmenistan	5.9	47	53	19	17
Uzbekistan	32.4	49	51	30	27

To protect agricultural productivity as well as Tugai forests and wetlands, reliable and sufficient water supply through reliable and sufficient river runoff from upstream is imperative, as agriculture depends on irrigation. In the course of climate change, substantial reductions of river runoff are expected for the second half of this century, resulting in crop yield losses, as summarized by Reyer et al. (2015). Bliss et al. (2014) for example modeled an annual river runoff decrease by 41% for Central Asia. Djumaboev et al. (2020) claim that the melt water contribution to river runoff dropped by 5% in the Amu Darya and by 20% in the Syr Darya. Against this background, water resources have to be shared between upstream and downstream users, and water must not be wasted to sustain productivity throughout river basins.

Large areas of cropland along those rivers have been degraded through improper irrigation which has resulted in soil salinization (Qadir et al. 2018). This process has to be halted, in order not to further reduce the area of land that has access to irrigation infrastructure and therefore can be productive. Beyond soil salinization, soils need to be protected from erosion and loss of humus to maintain soil fertility and water storage capacity.

In the desert areas, the Saxaul vegetation needs particular attention to be restored and protected, as it prevents wind erosion and is able to provide biomass and fodder in those deserts, if sustainably managed.

All Central Asian countries are net importers of wood (Table 2), with Russia being the main source for those imports.

Table 2. Net imports of sawnwood [m^3], industrial roundwood [m^3] (both coniferous), and OSB [m^3] and total import value of these three products [million USD] to the Central Asian countries as of 2018 (FAO 2020).

Country	Sawnwood Coniferous	Industrial Roundwood Coniferous	OSB	Total Value of Imports
Kazakhstan	315944	122,238	85,285	68.7
Kyrgyzstan	352,000	10,100	26,300	80
Tajikistan	683,000	15,760	550	39.4
Turkmenistan	344,000	12,994	2777	44.2
Uzbekistan	2,744,472	238142	2978	367

It is claimed that economies need to switch from coal, oil, and gas to renewable biological resources to mitigate climate change. In this shift, biomass will gain an increasing importance as a crucial raw material and the demand for biomass will increase (Global Bioeconomy Summit 2015). The countries in Central Asia should increase their wood and other biomass production, in order not to become more and more dependent on costly imports. The basis for such biomass production, e.g., food crops, fibers, or woody biomass, is functioning and non-degraded landscapes. This calls for large scale efforts to restore landscapes and protect non-degraded landscapes throughout the region Central Asia.

These restoration and protection efforts have to be inclusive and must not displace people or compromise their income opportunities. This is particularly important as most people live in rural communities and agriculture is the largest employer (Table 1). Such restoration and protection efforts must not displace ongoing land uses and water competition must be avoided, but income must be generated from restoration and protection efforts.

As biomass utilization will become more important in a general shift towards bio-economy, restoration as discussed further in this chapter should include trees and shrubs for woody biomass, highly productive annual plants for biomass, and fiber yielding plants. As forest landscape restoration has developed into a widely recognized restoration concept which focusses on trees and shrubs, this concept will be further explored.

3.2. The Political Environment for FLR and Other Landscape Restoration

There are a number of restoration concepts and approaches that integrate rural communities and their needs. Sustainable land management (SLM) collects a wide range of land use/land management approaches that also address restoration and protection of landscapes (WOCAT 2020). Forest landscape restoration (FLR) is a concept that takes whole landscapes into account and that has received global recognition under the international Bonn Challenge (IUCN 2020a).

"Forest landscape restoration (FLR) is the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes" (IUCN 2020b). Thereby, whole landscapes and not just forests (or areas with forests in the past) are considered for restoration, because forests interact with neighboring land uses and natural ecosystems and because many land uses contain trees (agroforestry). In Central Asia, the concept of FLR comprises a wide range of landscapes, along with the FAO definition of forests, which includes tree stands down to a canopy cover of 10% (FAO 2015). This is also reflected by the pledges made to the Bonn Challenge by Central Asian countries, which amounted to 2,389,000 ha in total (Bonn Challenge 2021). The largest pledge came from Kazakhstan with 1.5 million ha, followed by Uzbekistan with 500,000 ha. Both countries included large areas with Saxaul vegetation into their pledges. The five countries of Central Asia became members of ECCA30 (Europe, Caucasus and Central Asia 30 Million ha Initiative) which aims for FLR on 30 million ha throughout Europe, the Caucasus, and Central Asia until 2030 (IUCN 2020c).

Eventually, FLR and the pledges to the Bonn Challenge refer to trees or woody vegetation in a wide sense. Therefore, steppes and many wetlands will not fall under FLR and the Bonn Challenge. Due to their size and productivity, these areas have to be included in the restoration and protection of landscapes in Central Asia as well.

The countries in Central Asia have all developed and partly adopted national policy strategies that address the landscape restoration and protection needs outlined earlier, as listed by UNECE/FAO (2019).

Kazakhstan adopted the strategy Kazakhstan-2050 in 2012. Under that strategy, the whole economy of Kazakhstan shall move towards a green economy. Conservation and effective management of ecosystems are two parts of this strategy (UNDP 2015a).

Kyrgyzstan has developed a Green Economy Program 2020–2023, within which reforestation, fast growing tree plantations, and general improvement of soil fertility are core points (Partnership for Action on Green Economy 2019).

In Tajikistan, the State Forestry Agency elaborated a strategy for forest development for 2015 until 2030, as part of the National Development Strategy until 2030. This strategy, among other aims, seeks to plant 1000 ha forests annually, rehabilitating 2000 ha forests annually, and support natural forest regeneration on 8000 ha annually.

The National Forest Program 2013–2020 of Turkmenistan (State Committee of Turkmenistan for Environmental Protection and Land Resources 2018) prioritizes the restoration and afforestation of Saxaul forests, in order to combat erosion of deserts and protect settlements. Next to Saxaul, it promotes planting of shelterbelts.

In the National Biodiversity Strategy and Action Plan of Uzbekistan from 2012 (UNDP 2015b), the target was set to reduce the rate of degradation and fragmentation of the most vulnerable natural ecosystems by 2025. Thereby, the focus was laid on Tugai and Saxaul forests. In the mountain forests, degradation must be halted according to that plan as well. Nut and fruit plantations need to be established on a large scale, in order to offer income opportunities for rural communities and to compensate for degradation in the mountain forests. Around rural communities, woodlots and plantations are to be established to cover the wood demand of those communities.

3.3. Options for Restoration (FLR and Others) and Biomass Utilization

A huge number of projects were implemented across Central Asia, which included FLR as well as other landscape restorations, e.g., wetlands, as listed in UNECE/FAO (2019). Most projects focused on biodiversity protection and sustainable pasture/livestock management to reduce grazing pressure and allow, among others, forest regeneration, to combat erosion and reduce disaster risk, enlarge forest areas and increase the number of trees. Some projects focused on agroforestry as an FLR approach for agricultural areas. Some projects are coupled with providing alternative energy sources to reduce the pressure by fuel wood removal. When specific straight forward options for income generation were included, these mostly referred to fruits and other high value food products, medicinal plants, or tourism. An example of FLR that straight forwardly addresses income generation is promoting pistachio in lower elevations in mountains of Uzbekistan (Michael Succow Foundation 2014). FLR examples that aim at producing biomass as a raw material for material use have not yet been explored.

Therefore, underneath a number of FLR and other restoration approaches, ongoing and under development are introduced.

3.3.1. Agroforestry

Agroforestry comprises land use systems that integrate trees and shrubs into farming or animal husbandry. Agroforestry has a long tradition across Central Asia with trees integrated into silvo-pastoral systems, fruit trees integrated with crops, vegetables, or fodder, kitchen gardens, and tree wind breaks (Djanibekov et al. 2016). Thereby, tree wind break is the most widespread agroforestry system across the region in terms of area (Thevs et al. 2017a, 2019). In particular, during Soviet Union times, tree wind breaks were promoted and planted across whole Central Asia (e.g., Albenskii et al. 1972; Kort 1988; Thevs et al. 2019). Tree wind breaks, as other agroforestry systems, qualify as an FLR approach (IUCN 2020b), as they provide many benefits to landscapes to improve current and future biological productivity, which are reducing wind speed, thus reducing crop water consumption, acting as snow trap, combating erosion, increasing soil organic matter through leaf litter, and providing habitat for wildlife (Alemu 2016). Tree wind breaks do not displace ongoing land uses, such as food production, but integrate into such land uses.

The most common tree species used for tree wind breaks were poplars (mainly *P. nigra* clones), throughout the region, elm (*Ulmus minor*), in drier areas north of the Tianshan, and mulberry (*Morus alba*), in the Ferghana Valley and other parts of Uzbekistan, Tajikistan, and Turkmenistan.

All three tree species have been used as raw material, the former two for timber and fuel wood and the latter for silk production and for the wood. Today, most attention has shifted to poplar as fast growing tree in all countries and to mulberry as raw material for silk production mainly in Uzbekistan. These two tree species therefore offer opportunities to address restoration and provide domestic raw material and income opportunities, with a huge untapped potential for further raw material production as feedstock for bioeconomy.

An assessment of Kyrgyzstan revealed (Thevs and Aliev 2017) that a tree wind break grid of 500 m × 500 m across all cropland of the country would harbor 70 million poplar trees, which would cover most of the country's timber demand and a large share of the fuel wood demand. In this assessment, single row tree wind breaks were considered, as this is the type preferred nowadays by farmers. Still, this type significantly reduces wind speed and reduces agricultural water consumption (Thevs et al. 2019). Such single row tree wind breaks do not occupy much space so that there is very limited impact on ongoing land uses. Poplar wood can be used for a wide range of applications, as listed by Isebrands and Richardson (2014) so that an expansion of tree wind breaks would contribute to the raw material basis as needed for a bio-economy.

Mulberry yields the raw material for silk production as a high value product. Silk production has a history of thousands of years and was also promoted during Soviet Union times. Today, mainly Uzbekistan preserved domestic silk production and plans to modernize it, as was revealed by expert interviews in 2019 (Baier et al. 2019). Like poplars, mulberry trees can be integrated into ongoing land use as tree wind breaks. Furthermore, some mulberry cultivars have a certain salt tolerance so that they can be used as tree wind breaks on saline croplands or to restore areas of saline lands.

In the past three years, paulownia has been gaining increased attention as a fast-growing tree with very good timber properties. The timber is light and shows desirable mechanic properties DIN EN 338:2016-07 (DIN Deutsches Institut für Normung e. V. 2016). Currently, there are three plantations and single tree individuals in Kyrgyzstan, and further plantations are in the planning or establishment stage in Kazakhstan, Kyrgyzstan, and Uzbekistan. A group of paulownia trees in Bishkek observed during the growing season 2018 grew from 4.85 m to 7.70 m in height and from DBH of 8.9 cm to 14.6 cm on average (Villwock 2019). Three-year-old trees on the currently largest plantation in Kyrgyzstan, located at Lake Issyk Kul, grew from 2.70 m to 4.40 m in height and from DBH 5 cm to 7.9 cm in average during the year 2019 (Baier 2020). The vegetation period is shorter at Issyk Kul compared to Bishkek. Those trees at Issyk Kul showed a volume increment of 0.01 m^3 per tree compared to 0.004 m^3 volume increment of two-year-old poplars near Bishkek.

Paulownia was reported to have similar effects to poplars when planted as tree wind break, like wind speed reduction by 20–50% and reduction of evapotranspiration of 23–34% compared to open field conditions (Jiang et al. 1994). However, paulownia cannot be used as a tree wind break under very windy climates (Hecker and Weisgerber 2003). Paulownia, in contrast to poplar, cannot endure wet soils (Hecker and Weisgerber 2003). Therefore, Paulownia in combination with crops needs more careful irrigation management, in order to avoid wet soil conditions. Poplars can be easily combined with the widely spread flood or furrow irrigation, as it can endure wet soil conditions.

Whether Paulownia in agroforestry systems should be counted as FLR or not is debatable, as Paulownia is not an indigenous tree of Central Asia, and under humid climate conditions it has been reported as an invasive species. As paulownia needs to be irrigated under the climatic conditions of Central Asia, but cannot endure wet soil conditions, it depends on careful site management, which reduces its opportunities to germinate and recruit outside man-made sites.

Assuming timber yields at least as high as from poplars, paulownia offers similar opportunities to provide biomass as raw material for bio-economy, while providing benefits to landscapes in agroforestry systems and thus not displacing other land uses.

3.3.2. Salt and Water Stress Tolerant Plants for Degraded Croplands and Tugai Forests

Restoration of saline lands with halophytic plants has been implemented in many parts of the world, as e.g., listed by Qadir et al. (2018), including examples for Central Asia. If the resulting biomass is used, it is mainly used as fodder, often with low yields, as restoration is the main focus. Agroforestry was piloted with the tree species *Elaeagnus angustifolia*, *Ulmus pumila*, and *Populus euphratica* on saline degraded lands in Khorezm, Uzbekistan by Lamers et al. (2008). These agroforestry systems were established to yield fodder, fuel wood, and fruits from *Elaeagnus angustifolia.*

Two further promising candidates for restoration of saline lands in river plains are licorice (*Glycyrrhiza glabra*) and Kendir (*Apocynum venetum*). Both plant species are part of the natural vegetation of the river plains and Tugai forests of Central Asia. Both are adapted to the arid climate by tapping the groundwater (phreatophytes) for their water supply. This makes them endure years with low river runoff, as the groundwater layer stores water and acts as a buffer for those plants. Furthermore, both plant species have a certain salt tolerance so that they can be planted on areas which cannot support food production to an economically viable level.

Licorice yields fodder from its leaves, but the higher value biomass are the roots, which are a raw material for medicinal products and for flavors to foods and beverages. As licorice is a nitrogen fixing plant (Fabaceae), it helps improving soil fertility (Kushiev et al. 2005).

Kendir yields bast fibers of a quality similar to cotton and can be harvested as a medicinal plant, which makes it a plant species with the potential to yield high value raw material from places with not many other land use alternatives. Kendir was cultivated until the 1950s in today's Uzbekistan, but abandoned in favor of cotton. Fiber processing after cotton harvest (ginning) is technically easier than the extraction of a bast fiber like Kendir. However after improper irrigation, this has resulted in large areas of saline lands, which do not support high cotton yields anymore. Kendir is salt tolerant, and could be an alternative for those lands, providing a much more valuable raw material than fodder or fuel wood (Thevs et al. 2012b).

3.3.3. Reed as Biomass Source

Central Asia, despite its semi-arid to arid climate, has globally large reed bed areas which yield a huge amount of biomass. Kazakhstan alone harbors 2 million ha of reed beds, followed by Uzbekistan and Turkmenistan with several hundred thousand Hectares each (Köbbing et al. 2013). The Ili Delta in Kazakhstan, which is one of the largest reed bed areas of the region, was mapped through remote sensing (Thevs et al. 2017b), which revealed an area of submerged and non-submerged reed of 85,400 ha and 126,378 ha, respectively, with a standing stem biomass of 869,097 t in the submerged reed beds. The resulting average biomass of 10.1 t/ha is in the range of reed biomasses reported for other reed beds across Kazakhstan (Baibagyssov et al. 2020). This allows the conclusion that there is a huge biomass pool that can be tapped as raw material for the bio-economy, even if only a part of that reed is used, in order to give space to biodiversity conservation.

Reed yields a ligno-cellulose biomass, which can be used as raw material for paper, paper board, and OSB boards. A small factory for OSB boards is being built up in the Ili Delta. Cellulose extraction and the subsequent production of sugars and further chemical inputs are under research, as compiled by Schäpe (2016).

4. Conclusions

Central Asia, despite its arid climate and manyfold land degradation, offers potential for sustainable utilization of biomass as feedstock for different products and value chains under bioeconomy approaches. The options for biomass utilization introduced here avoid or minimize competition with food production. Agroforestry, which includes poplars, mulberry, or paulownia offers timber and silk as high value product. On saline lands, agroforestry offers less valuable products, but still offers options to make use of such lands. Moreover, Kendir and Licorice are plants that yield high value products (fibers, medicine, and flavors) from saline land, which otherwise poses difficulties to grow food crops. Finally, reed in the wetlands of the region yields huge amounts of ligno-cellulose biomass, which can be used as raw material for paper, paper board, and OSB boards. Thereby, the processing of wood and silk as raw materials from agroforestry are well known. The utilization and processing of Kendir and reed though still needs some research to unfold their full potential for high value products.

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