

ACCELERATING BIOECONOMY AND CIRCULAR ECONOMY IN CENTRAL ASIA: INVESTMENTS AND SUSTAINABLE RESOURCE MANAGEMENT

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Abstract (English)

This paper examines the development of the bioeconomy and circular economy in Central Asia (Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan) over 2005–2025. Drawing on literature and recent data, it analyzes how sustainable resource management and investments can drive the green transformation in the region. We find that Central Asian countries are at an early stage of circular transition: key indicators such as resource productivity are low and waste recycling rates barely reach ~10–12% of municipal solid waste (cf. ~45% in the EU). Renewable energy deployment has increased – installed renewable capacity in Uzbekistan grew by 174% between 2015 and 2024 (from ~1.9 to 5.2 GW) – but fossil fuels still dominate (OECD, 2024). Strategic public policies (like PPPs and regulations) and targeted investments are shown to significantly boost transition. For instance, World Bank studies recommend action plans in agriculture and construction (Uzbekistan, Kazakhstan) that yield high returns: improving resource efficiency in Uzbek agri-food could cut GHG by 34% and create ~46,000 jobs. Case studies illustrate best practices: large-scale solar PV¹ auctions in Uzbekistan (aiming for 4 GW by 2026); hydropower projects in Tajikistan; and pilot recycling programs in Almaty. Overall, we conclude that leveraging green investments – including public–private partnerships and de-risked finance – alongside stricter waste management and renewable energy policies will accelerate the circular bioeconomic transition in Central Asia. A strong regional focus on investment in clean tech and efficient resource use is key to achieving sustainable economic growth.

Аннотация (Russian)

В данной работе рассматривается развитие биоэкономики и циркулярной экономики в Центральной Азии (Казахстан, Узбекистан, Кыргызстан, Таджикистан, Туркменистан) за 2005-2025 годы. Основываясь на литературе и последних данных, он анализирует, как устойчивое управление ресурсами и инвестиции могут способствовать зеленой трансформации в регионе. Мы обнаруживаем, что страны Центральной Азии находятся на ранней стадии

¹ Photovoltaics (PV) is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry.

циркулярного перехода: ключевые показатели, такие как продуктивность ресурсов, низкие, а уровень переработки отходов едва достигает ~10-12% от муниципальных твердых отходов (ср. ~45% в ЕС). Использование возобновляемых источников энергии увеличилось - установленные возобновляемые мощности в Узбекистане выросли на 174% в период с 2015 по 2024 год (с ~1,9 до 5,2 ГВт), но доминирующим остается ископаемое топливо (ОЭСР, 2024). Показано, что стратегическая государственная политика (такая как государственно-частное партнерство и регулирование) и целевые инвестиции значительно способствуют переходу. Например, исследования Всемирного банка рекомендуют планы действий в сельском хозяйстве и строительстве (Узбекистан, Казахстан), которые приносят высокую отдачу: повышение ресурсоэффективности в узбекском агропродовольственном секторе может сократить выбросы парниковых газов на 34% и создать ~46 000 рабочих мест. Примеры иллюстрируют передовой опыт: крупномасштабные аукционы на солнечные фотоэлектрические станции в Узбекистане (цель - 4 ГВт к 2026 году); проекты в области гидроэнергетики в Таджикистане; и пилотные программы по переработке энергии в Алматы. В целом, мы пришли к выводу, что использование зеленых инвестиций, включая государственно-частное партнерство и безрисковые финансы, наряду с более строгим управлением отходами и политикой возобновляемой энергетики, ускорит циркулярный биоэкономический переход в Центральной Азии. Сильное региональное внимание к инвестициям в чистые технологии и эффективное использование ресурсов является ключом к достижению устойчивого экономического роста.

Introduction

The concepts of bioeconomy and circular economy represent a shift away from traditional “take-make- waste” economics toward sustainable resource use. In a circular economy, materials flow in closed loops: wastes and by-products are recycled, reused or biologically treated to extract value. In the bioeconomy, renewable biological resources (crops, forests, waste biomass) are harnessed for food, materials, bioenergy and biochemicals, ideally with low-carbon processing and minimal ecological impact. As Tan and Lamers (2021) note, the goal is to “slow, narrow, and close” material loops using renewables, and to couple this with non-toxic, low-carbon technologies. This integrated “circular bioeconomy” can create new value chains while capturing carbon and preserving ecosystem health.

Central Asian economies have traditionally relied on extraction industries and intensive agriculture, with resource productivity far below global averages. For

example, Kazakhstan's material productivity is only ~ €0.2 GDP per kg of domestic material (vs ~ €2.1 in the EU). Rapid growth has led to increased energy use, waste generation and resource depletion. Meanwhile climate change and water scarcity pose rising risks. In this context, circular and bioeconomic strategies are increasingly seen as pathways to sustainable development. The 2030 Agenda for Sustainable Development (SDGs) and the Paris Agreement imply transitions to low-carbon, resource-efficient models. Central Asian governments have begun adopting green economy targets and climate commitments (Uzbekistan's Green Economy Strategy 2019–2030 and carbon-neutrality pledges by 2060).

This paper investigates how accelerated investment and improved resource management can catalyze bio- and circular economy transitions in Central Asia. We integrate global best practices and regional case studies from 2005–2025 to identify opportunities and challenges. Key questions include: What are the recent trends in renewable energy, waste recycling, and bio-based industries in Central Asia? How effective have policies and investments been? And critically, how can financing and sustainable management of resources fast-track the shift to a green economy in the region?

Literature Review

Previous studies highlight both the untapped potential and current gaps in Central Asia's green transition. The World Bank (2024) finds that all five Central Asian countries score low on circular economy metrics. Recycling rates of municipal solid waste (MSW) are around 11.5% in Kazakhstan and below 10% in Uzbekistan (versus ~45% in the EU). Resource efficiency is similarly poor: Central Asian resource productivity is roughly an order of magnitude lower than in Europe. Waste management infrastructure and policies remain underdeveloped, and public awareness of circular practices is low.

World Bank reports (CEAPs – Circular Economy Action Plans) have proposed sector-specific plans for the region. For Kazakhstan's construction sector and Uzbekistan's agri-food sector, action plans emphasize improving material efficiency, designing eco-products, and closing production-consumption loops. These studies estimate that the long-term benefits (GHG cuts, water savings, jobs) substantially exceed implementation costs. For example, the Uzbek agri-CE² plan could reduce agricultural emissions by 34% and save 500 million m³ of water. Such analysis suggests high returns on green investments, but also highlights barriers: financing gaps, technology limits, and regulatory inertia.

² Agri-CE – Agri-circular-economy

At the national level, bioeconomy policies have recently emerged. Raimjanova and Popluga (2023) examine Uzbekistan's agro-bioeconomy and find that agricultural investment soared ~176-fold from 2002 to the 2020s, greatly boosting output. However, they argue that new state programs are needed to channel further investment into biotechnologies, renewable biofuels and circular agro-processing to sustain momentum. In Kazakhstan and other CA states, research on circular entrepreneurship and industrial symbiosis is limited but growing. Empirical work by Wu and others (2023) on the "green recovery" in five CA economies (2010–2021) indicates that trade openness in green goods correlates with better environmental performance, whereas aggregate FDI has not automatically delivered green outcomes. They recommend targeted green FDI and innovation support.

Global literature provides context: the circular bioeconomy is projected to be a multi-trillion-dollar market by 2030, driven by repurposing bio-waste into energy and materials. Leading-edge companies and cities demonstrate how urban waste, organic residues and forestry by-products can be valorized through advanced biorefineries, composting, and recycling systems. For instance, the Ellen MacArthur Foundation and WBCSD document numerous case studies of closed-loop systems (agro-waste-to-bioenergy in China or Finland's forest bioeconomy) and principles for circular design. Key enablers include public–private partnerships, innovative financing, and supportive regulation. Conversely, major obstacles globally are financial (high upfront costs), technological, and institutional (policy gaps). These themes resonate in the CA context.

Methodology

This study synthesizes qualitative and quantitative sources to assess the bio/circular economy in Central Asia. We conducted a comprehensive literature review of policy papers, academic articles, and reports (UN, World Bank, OECD, IRENA, etc.) published from 2005 through 2025. Key indicators – such as renewable energy capacity, investment flows, waste recycling rates, and related economic data – were drawn from these sources. Where possible, data were cross-checked against national statistics and international databases. Several region-wide and country-specific case studies were identified (Central Asia CEAPs, national strategies, project reports) to illustrate real-world initiatives.

To address the focal question on investments and sustainable resource management, we categorized findings into thematic areas: finance and policy (public/private investment, green funding instruments), resource efficiency practices (water, energy, waste), and value-chain examples (agriculture, industry).

The comparative analysis highlights differences among countries and draws lessons from global best practice. Although this is a review rather than an empirical field study, we apply a structured framework by mapping case studies against theoretical circular-bioeconomy models (inputs-processing-outputs loops) to interpret how investments translate into outcomes.

Discussion

Investment Trends and Policy Incentives

Investments in green infrastructure are critical but currently low. The OECD (2024) notes that Central Asian energy investment remains heavily fossil-fuel-based (93% of recent energy investment in Turkmenistan, 79% in Kazakhstan was fossil-related). In contrast, Uzbekistan and Tajikistan have started mobilizing substantial funding into renewables and efficiency. For example, Uzbekistan conducted competitive tenders (2019 onward) that attracted foreign capital to build ~2 GW of solar PV. International financial institutions (World Bank, ADB, EBRD) have co-financed many projects. Government policy has also shifted: Uzbekistan's 2019 Laws on Renewable Energy and PPP provide tax incentives for solar and wind projects. Similarly, Kazakhstan's national targets (carbon neutrality by 2060) have indirectly spurred green fund schemes. Nevertheless, private investment often remains below potential. High perceived risk and lack of local expertise limit scale-up. Studies (WBCSD³, 2023) stress the need for blended finance instruments and de-risking to draw capital (barriers include "additional costs" and "policy and regulatory" hurdles).

Resource Management and Circular Practices

Resource management in CA has traditionally prioritized extraction and supply over efficiency. However, rising resource prices and climate impacts are changing this calculus. Agriculture is a focal point: countries like Uzbekistan and Tajikistan are implementing precision irrigation and introducing drought-resilient crops to combat water scarcity. Circular solutions (using crop residues for compost or energy) are gaining attention. For instance, a World Bank CEAP found that closing nutrient loops in Uzbekistan's agri-chain (reusing plant waste as biofertilizer) could cut GHG by ~ 34% and save major inputs. Implementation would require investments in storage, processing facilities and training. Similarly, in livestock farms, digesters could recycle manure into biogas; however, pilot projects show little existing biogas capacity in the region due to technical challenges (REPIC, 2019).

³ World Business Council for Sustainable Development

In the industrial and construction sectors, material efficiency is increasingly recognized. The World Bank's analysis of Kazakhstan's construction chain highlights that nearly 30% of building materials were imported in 2019 and that waste handling is largely traditional landfilling. Introducing secondary materials and waste sorting can both cut costs and emissions. Some positive steps exist: Kazakhstan's environmental code (2021) encourages recovery of construction waste, and infrastructure for recycling is slowly expanding. Waste management overall remains underdeveloped. Current recycling of household and industrial waste is low, and landfill usage is high. For example, plastic pollution is rising in urban areas. Uzbekistan's Ministry of Ecology reports that in 2022 the country generated 10.2 million tons of municipal solid waste, of which ~1.05 million tons (10.3%) was plastic – up 147% from 2013. Yet only a small fraction of that is recycled. Similar trends hold for other streams: food waste is often sent to landfills, and e-waste recycling is nearly non-existent. These gaps point to major opportunities: basic measures like expanding sorting facilities, mandating extended producer responsibility (EPR) for plastics, and incentivizing composting could substantially improve material loops. In fact, Uzbekistan has begun an EPR scheme for plastic products (2024) to ensure producers finance collection and recycling.

How Investments Accelerate Transition

There is growing evidence that targeted investments produce multiplier effects toward circularity. Infrastructure spending in renewables or waste treatment often creates green jobs and new industries. For instance, solar farm projects in Uzbekistan since 2019 have not only added capacity but also transferred know-how to local utilities, and required networking of remote areas, indirectly improving grid efficiency. The Asia-Plus report (2025) notes that in 25 years of independence Tajikistan's energy sector projects (worth ~\$8.5 billion) have led to a 45% increase in capacity and a 22.4 TWh output (up from 17.0 TWh in 1991) – largely through hydropower. Such infrastructure investments clearly payoff: more stable power supply and displaced diesel generation, contributing to carbon reduction.

Beyond hardware, financial and fiscal reforms matter. Wu and others (2023) show that intra-regional green trade and investment openness positively affects CA's "green recovery," whereas blanket FDI tends to favor traditional industries. The implication is that policy must guide investment into the right channels. Uzbekistan's rapid expansion of renewable targets (4 GW solar and 4 GW wind by 2026, and an even higher aim of 8 GW by 2026 announced in COP26 pledges) reflects this strategy. Similarly, Armenia and the EU's Green Deal are cited as

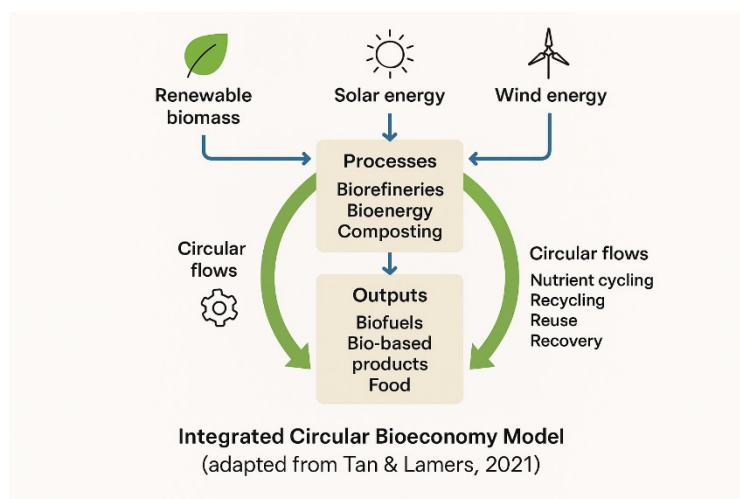
models where carbon pricing and subsidies redirect finance; CA countries are only beginning similar schemes (e.g., Kazakhstan's nascent ETS).

Global Best Practices and Regional Relevance

Global experiences underline the potential of circular bioeconomy strategies. In the EU, cross-sector policies enable agriculture residues to feed bio-refineries (making bioplastics, bioenergy) and industry waste to be reused (industrial symbiosis). Advanced metrics (e.g., carbon accounting) are used to justify investments. The WBCSD (2023) report emphasizes that the total economic opportunity in the circular bioeconomy could reach ~\$7.7 trillion by 2030 if businesses fully valorize food and feed waste. Applying such a lens to Central Asia, one can imagine using abundant bioresources – cotton stalks, sugar beet pulp, fruit pomace, animal manure – as inputs for new value chains (biogas, bio-composites, organic fertilizers).

Figure 1

However, CA-specific constraints (fragmented land ownership, limited technical capacity) mean solutions must be tailored. For example, rather than capital-intensive biorefineries, decentralized approaches (community composting hubs, cluster biogas units for groups of farms) could be more feasible.



Policy roadmaps (like the World Bank CEAPs for Almaty's city waste or Uzbekistan's agriculture) suggest practical steps: regulatory standards for recycled content, subsidies or loans for waste recycling plants, and public– private demonstration projects.

Case Examples

1. Uzbekistan – Agri-Bioeconomy: Uzbekistan has embarked on large-scale solar and wind deployment. According to IRENA, installed renewable capacity jumped from 1.88 GW in 2015 to 5.17 GW in 2024, largely through public auctions attracting foreign investors. Concurrently, the government aims to incorporate circular principles in agriculture: the 2020–2030 Strategy for Bioeconomy encourages R&D in biotechnology and biofertilizers. The CEAP for the Uzbek agri-food chain (2022) identifies projects like sorting facilities for post-harvest loss reduction and pilot biogas plants on large farms. An estimated 0.5 bn

m³ of water could be saved annually by such measures, alongside huge GHG cuts (34% in agriculture) and up to 46,000 new jobs. Financing is envisaged through PPPs and green bonds. Challenges remain in mobilizing finance at needed scale: even with these plans, Uzbekistan's recycling rate stays near 10% and major industrial recycling is rare. Still, pilot programs (Uzbek-British projects on recycling textile waste) show promise.

Table 1: Renewable Energy Share (% of Electricity Generation) in Central Asia (2005–2025)⁴

Country	2005	2010	2015	2020	2025
Kazakhstan	11.58%	9.71%	8.87%	10.4%	15%(target)
Uzbekistan	17.54%	20.98%	20.65%	18%	40%(target)
Kyrgyzstan	85.88%	91.80%	85.19%	90%	Stable
Tajikistan	99.28%	99.79%	98.47%	95%	Stable

2. Kazakhstan – Construction and Industry: The World Bank CEAP identified construction as a priority. Recent laws (Environmental Code 2021) ban dumping of construction and demolition (C&D) waste in open sites and require recycling where possible. In practice, one pilot recycling yard for concrete debris was opened in Almaty in 2021, selling recycled aggregate to local builders. Meanwhile, Kazakhstan continues large hydropower and wind projects (a 1.3 GW wind farm launched in 2023). On the bio side, Kazakhstan's vast steppe offers biomass opportunities: some projects convert wheat straw and sawmill waste into biochar and bioenergy, though mostly at experimental stage. The government also supports algae farms for carbon capture. Investors have shown interest: IFC and others have financed renewable projects and circular startups (cardboard packaging recycling businesses). Still, systematic data on waste recycling investments is sparse; one indicator is that municipal solid waste recycling (~11.5%) is slowly inching up as new sorting centers open in Astana and Almaty.

3. Kyrgyzstan and Tajikistan – Hydropower and Small-Scale Bioenergy: Kyrgyzstan and Tajikistan depend heavily on hydropower (75–90% of their electricity). Recent plans e.g., Rogun Dam in Tajikistan) focus on expanding renewable generation. In Tajikistan, the president announced 36 large energy projects worth \$8.5 billion since 1991, including modernizing old dams. These raise total capacity but less so per-capita output. Given seasonal water variability, both countries have begun diversifying: small solar PV farms (e.g., 100 MW plant in Tajikistan in 2022) and pilot wind turbines. They also have nascent biogas initiatives: a 2020 World Bank project funded small biogas digesters on Kyrgyz

⁴ <https://www.macrotrends.net/global-metrics/countries/>

farms to reduce coal use for heating. While by themselves minor, these illustrate how targeted investment (even from donors) can introduce new green technologies.

4. Almaty, Kazakhstan – City Waste Management: As a case of circular urban management, Almaty's waste CEAP (2022) examined three material-intensive sectors. It recommended investments in landfill-gas-to-energy plants, central sorting facilities, and modular housing built from recycled materials. Since then, Almaty has tendered for a 100 MW waste-to-energy plant (PPP basis) and launched public awareness campaigns on recycling. Though still preliminary, this exemplifies a holistic city-level approach supported by international finance (Green Climate Fund, etc.) to accelerate circular practices.

5. Global Best Practice – European Bioeconomy: For context, consider the EU Bioeconomy Strategy (revised 2018) which bundles agriculture, waste and energy policies to support biorefineries, bio-based products and rural bio enterprises. EU member states often mix subsidies (feed-in tariffs for biogas, rural development grants) with strict landfill taxes, creating economic incentives for reuse. An illustration: Finland's forest sector systematically recycles wood residues into wood-based textiles and bioproducts (cellulose insulation, bio-methanol) through partnerships between industry, research institutes and government. In Asia, Thailand's BCG (Bio-Circular-Green) model promotes similar integration. Central Asia can learn from these by creating multi-stakeholder platforms (linking farmers, processors, NGOs) and by adjusting subsidies (e.g., lower tariffs for biofuels, tax breaks for recycled inputs).

Conclusion

The evidence indicates that investments and resource management can indeed accelerate Central Asia's green transition. Region-specific analyses and case studies show that where funding and policies align – in renewables, bio-based industries or waste recycling – significant gains are realized. Yet many opportunities remain unrealized. Recycling rates are low and underinvestment is chronic (OECD, 2024). To bridge this gap, Central Asian governments should continue to develop clear roadmaps (as in World Bank CEAPs) and establish innovative financing (green bonds, blended funds) that leverage private capital. Emphasizing sustainable resource management – for instance, enforcing waste collection, modernizing irrigation and forestry practices – will reduce input costs and mitigate environmental damage.

Answering the central question, our review suggests: accelerating bio and circular economy transitions requires coupling strategic investments with systemic changes in resource use. On one hand, investments (public and private) in

renewable energy, modern bio-industries and waste infrastructure directly build the needed capacity. On the other, integrated policies and incentives shape how these resources are managed – for example, by valuing recycled material, rewarding efficiency, or penalizing waste. When combined, these measures can create a virtuous cycle: new green projects spur economic growth and job creation, which in turn justify further investment. Central Asia's abundant natural and human capital means that with proper funding and governance, a more circular, bio-based economy is attainable.

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