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WHEY VALORIZATION OPPORTUNITIES IN KYRGYZSTAN: APPLICABILITY OF CIRCULAR ECONOMY PRACTICES

S u m m a r y

Background. Cheese whey is the main by-product of dairy processing and is still discarded as waste in many countries, including Kyrgyzstan. Yet whey contains high-value proteins, lactose, minerals and bio-actives that can be recovered through circular-economy business models (CEBMs) and converted into food ingredients, biomaterials or energy. Whey can be valorized along three circular-economy pathways such as food-ingredient recovery (whey-protein concentrate/isolate and edible lactose), material conversion to ethanol, lactic acid, polyhydroxyalkanoate bioplastics and polyurethane polyols, and energy-and-nutrient recovery through anaerobic digestion followed by struvite fertilizer production. A qualitative case study was carried out at three largest dairy plants in the Issyk-Kul region. On-site audits and semi-structured interviews mapped whey volumes, current disposal routes and managers' views on valorization.

Results and conclusions. The plants together generate \approx 156 tons of liquid whey per day, but only one spray-dries about 1 ton/day into powder. The remainder is used as low-value animal feed or discharged after minimal treatment. National demand for processed whey is nonetheless rising: imports of whey powder grew from 0.09 kt in 2020 to 1.47 kt in 2023. Interviewees identified three CEBMs as technically feasible: a hub-and-spoke toll-drying scheme, leased membrane equipment for on-site whey concentration, and manure-plus-whey co-digestion for biogas and struvite fertilizer. The impediments to whey valorization mirror global barriers, including inadequate investment, lack of managerial support, absence of governmental regulation, seasonal and scattered milk supply, weak cold-chain logistics and deficiency in technological

Keywords: whey valorization, circular economy business models, Kyrgyzstan, dairy processing, dairy by-products

Introduction

Currently, most businesses use the dominant linear development model, also known as “take-make and dispose.” However, with the increasing speed of climate change and scarcity of resources, this model of development is questioned and consid-

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ered unsustainable. The Brundtland Commission, formerly the World Commission on Environment and Development (WCED), initiated the Brundtland report, also known as “Our Common Future”, in 1987, a seminal document that raised the significance of the issues concerning sustainable development [31, 51]. The main aim of the report was to establish a middle ground between a boundless philosophy of economic growth and dire environmental and social risks forecasted by authors such as the Club of Rome [51]. In other words, the independent Commission of Brundtland sought to balance the continuous economic development worldwide with the finite resources of the environment, which were predicted to lead to catastrophic consequences [31, 51]. Murray et al. [31] state that while the “Our Common Future” report was being published, numerous Western governments started embracing neo-liberal economic policies. It led to free-market oriented policies with minimal government intervention in the economy. As a result, while some part of the world called for reducing the consumption of goods and services for the sake of sustainable development, the actual outcome was that capital markets got globalized, banks were deregulated, information technology advanced and production was outsourced.

Thus, the life-support systems of the Earth are increasingly jeopardized by such factors as a biodiversity loss, excessive natural resources utilization, inadequate responses to global warming and pollution of soil, air and water. Whether due to the complexity of these issues, a lack of guidance, or alternative business models failing to provide viable solutions, there is an imperative need to shift towards sociotechnical systems that are more sustainable compared to the prevailing linear model of extracting, producing and discarding materials and energy in the modern economic system [14, 24, 31]. This concept entails the intentional and deliberate design of an industrial system that aims to restore or regenerate finite resources and can be used as a possible strategy to face the challenges described above [17, 31].

The concept of the circular economy (CE) has emerged as a significant area of academic research, evidenced by a notable increase in scholarly articles, journals, and books. This concept has been extensively discussed by various scholars, practitioners, and researchers over the last decade [14, 17, 51]. While the definition of CE remains debated, with some scholars arguing that it has not been “commonly accepted,” there is a general consensus that the term broadly refers to the process of optimizing resource use and minimizing waste [17, 22, 51]. Nevertheless, Velenturf et al. [51] highlight that the interpretation of “better” resource use is subjective and varies among scholars.

Murray et al. [31] suggest that while the precise origins of the circular economy terminology are difficult to trace, the concept likely evolved from long-standing ideas within the field. For instance, the Royal Society of Chemistry posited that an ideal chemical factory would produce no waste by-products. Geissdoerfer et al. [30] note the

influence of Boulding's 1966 work, which advocated for a closed-loop system on Earth to achieve a balance between the environment and the economy.

Murray et al. [31] further suggest that the term "circular economy" has both descriptive and linguistic meanings. Linguistically, CE can be understood as the antonym of a linear economy, which involves extracting natural resources and converting them into waste, ultimately causing significant environmental damage. In other words, CE can be defined as a "regenerative system in which resource input and waste, emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling" [5]. By transitioning from a linear to a circular model, the economy aims to achieve a zero environmental impact by mitigating damage caused during resource extraction and ensuring minimal waste generation during production. Descriptively, CE encompasses the concept of cycles, emphasizing the continuous flow and reuse of materials [31].

Circular Economy Business Models

The concept of the business model was formulated in the 1970s and has undergone continuous evolution since its inception. Presently, amidst a notable shift towards sustainability and the adoption of circular economy principles, the discourse surrounding the CEBM has garnered significant attention and scrutiny within various academic inquiries.

A business model is a key element of a company, serving as a guiding framework that addresses fundamental questions pertaining to the Who, What, How and Why of business operations. The primary dimension of the business model is WHO is the customer? Customers are at the center of any business model, and the company must clearly identify the customer segment it serves. The second dimension is the value proposition, or WHAT products/services the company offers. The third pillar is the value chain, or HOW the company produces its products or services. The final dimension is the profit mechanism, which identifies how the company's business model becomes commercial and profitable [13].

Oliver Gassman argues that a significant factor contributing to business failure is the absence of innovative elements within business models. To be successful, a company must build its competitive advantage based on an innovative business model. According to Gassman, innovation in the business model can be achieved only if it changes at least two out of the four dimensions of the business model [13].

Therefore, the current need for circularity in businesses is extremely important as it not only helps decrease the negative impact on the environment but also builds and improves the competitive advantage of the business. The aim of any type of business is to provide value for its customers, and a circular business model can be defined as a

system through which companies “create value, capture value, and deliver value to stakeholders through the conversion of scarce resources” [16]. A circular economy business model must be structured in a way that aligns with the definition of circularity and adheres to its underlying principles. Different researchers agree that value creation, value transfer and value capture are the three pillars on which a sustainable business model is built. Value creation involves the production of products and services that, in light of the circular economy, encompass not only economic value but also environmental benefits. Value transfer refers to the sustainable promotion of these products and services and the communication of circular initiatives through various channels. When value is created, the challenge is to retain its value; in other words, how the company can generate revenue and what its cost structure entails [2, 3]. Geissdoerfer et al. [14] in their research on circular business models, developed a framework for the circular economy that identifies three main conditions for sustainability: economic, social and environmental dimensions, proactive stakeholder management and a long-term perspective.

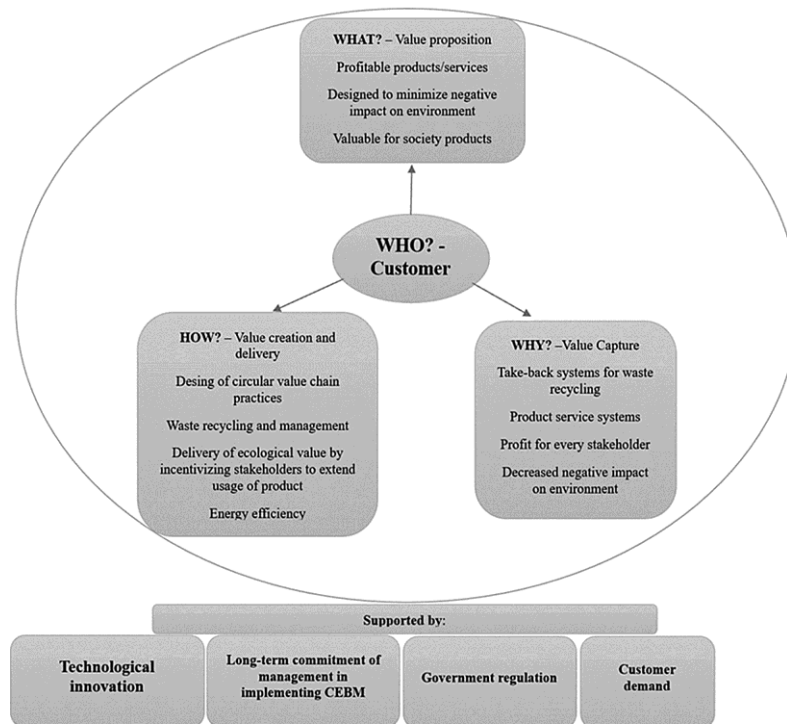
In response to the global challenges related to scarce resources and waste utilization, the concept of the circular economy has promoted several business models that can be adopted not only to achieve sustainable development, but also to create jobs and dematerialize the industrial economy. Common approaches of these business models typically involve “reusing, refurbishing, repairing, sequential use, rental or leasing, collaborative consumption and resource optimization” [15]. In essence, these circular economy business models aim to slow or close the loop of resource consumption, enabling economic actors to maintain the value of products, goods and materials, and utilize them to their fullest potential at all times [15, 49].

Studies of various case studies indicate several determinants for the effective introduction of these business models. Ranta et al. [39], through a comprehensive examination of multiple case studies on business models, outlined five principal propositions for CEBM. These propositions encompass cost efficiency, the necessity of incentivizing take-back services to encourage customers in waste volume reduction, a varied array of implementation strategies, the diversification of value chains within such enterprises, and the assertion that recycling represents the most straightforward principle of circular economy initiatives.

Rizos et al. [43] outline several barriers in implementing CEBM. These barriers include a lack of supply from suppliers and customers, insufficient investments and government support, administrative burdens, and a lack of technological innovation. At the same time, their research indicates several enablers of the CEBM, which include the company's internal culture, networking, profitability of the CEBM and external recognition from society. Geissdoerfer et al. [15] in their study of drivers and barriers

categorize these barriers into financial, legal, market, technical, organizational and value chain categories.

The main dimension of the traditional linear business model is profit maximization. After analyzing various studies on CEBM, we conclude that CEBM is based on three pillars: economic (profit maximization), environmental and social. To build an effective CEBM, businesses should deliver valuable products/services to their clients, produced with minimal waste by designing circular supply chains, extending product shelf life and minimizing resource usage. After reviewing the various researches on CEBM, we developed the following CEBM framework, presented in Figure 1.



Explanatory notes: Source: Adapted from [1,3,14,15, 17, 24, 25]

Figure 1. Circular economy business model framework

Rycina 1. Ramy modelu biznesowego gospodarki o obiegu zamkniętym

Overview of the world's dairy industry

According to projections by the OECD and FAO, dairy product consumption will increase by 0.4 % in developed countries, 2 % per annum in middle-income countries, and 1.5 % per annum in low-income countries by 2031 [33]. Milk production is con-

sidered to be the fastest-growing food production sector, with an annual increase of 1.8 % over the next decade. However, dairy production “accounts for a substantial share of overall greenhouse gas emissions (GHG), resulting in discussions on how adjustments to dairy production could contribute to reducing such emissions” [33].

Many researchers contend that one of the main by-products of the dairy industry is whey, which, in many countries, is treated as waste. However, numerous studies show that whey is a valuable by-product. Whey contains valuable nutrients such as functional proteins and peptides, lipids, vitamins, minerals and lactose that can be effectively utilized and harnessed [50]. With the help of recent technological developments, whey can be effectively valorized and consumed by the population.

As the dairy industry expands, wasted whey poses a notable pollution risk. If left unaddressed, this issue has the potential to intensify and become increasingly challenging to mitigate in the long run. Wasted whey poses a considerable threat to the environment due to its high biological oxygen demand. Because of the high concentration of lactose, whey is the most polluting food waste, with a biochemical oxygen demand (BOD) of 435,000 ppm and a chemical oxygen demand (COD) of 460,000 ppm [46]. Consequently, prioritizing appropriate methods for further processing whey is of paramount importance. Failing to recognize the inherent value of whey and treating it as mere waste results in the loss of a highly nutritious substance, while simultaneously inflicting significant contamination of land and water ecosystems.

Simultaneously, the dairy industry's progress in advanced production methods has facilitated the exploration of further applications for whey and the development of new technologies aimed at producing whey-based products. This trend is supported by the increasing world population, resulting in growing interest among food manufacturers in additional food nutrients. Moreover, the demand for whey protein is driven by consumer interest in a healthy lifestyle and diet. In 2011, the global whey protein market was valued at USD 10.26 billion, with projections to grow from USD 11.0 billion in 2022 to USD 18.12 billion by 2032 [52].

Whey composition and its biological properties

Whey is a yellowish liquid by-product obtained after the production of cheese, quark, or casein. It exists in two main forms: sweet whey with a pH around 5.6 and acid whey with a pH approximately 4.5. As a residual from dairy processing, whey constitutes 80 ÷ 85 % of the original milk volume and retains about 55 % of the milk's essential nutrients [41]. Over recent decades, researchers have explored various avenues for recycling whey. Advances in technology have led to numerous methods for processing whey, transforming it into valuable products and ingredients.

The primary constituent of whey is lactose. In addition to lactose, whey contains proteins, minerals, B-complex vitamins and other bioactive compounds [36]. Initially

treated as a waste product in the 1960s, the development of whey powder extraction methods in the 1970s provided an additional revenue stream of approximately USD 1 per kilogram for the dairy industry. Today, advanced techniques for enriching whey fractions have the potential to generate even higher revenues, ranging from USD 18 to USD 300 per kilogram [50]. The following table presents comprehensive data on the composition of whey derived from various studies, underscoring the nutritional value of whey and emphasizing its potential beyond mere waste disposal. Whey serves as a valuable resource capable of not only increasing revenue for dairy companies but also delivering essential nutrients to consumers [38]. Thus, whey processing stands as a prime example of circular business practices.

β -Lactoglobulin is a predominant whey protein absent in human milk. It serves as a significant source of amino acids and is the primary allergen in milk, although modifications can render it non-allergenic and even inhibit allergic responses rather than provoke them. α -Lactalbumin, the second most abundant protein in whey, boasts a rich mineral profile and favorable amino acid composition. It exhibits chelating properties with cations such as Mg^{2+} , Mn^{2+} , Na^+ and K^+ , and research indicates its role in supporting immune function, aiding stress relief, regulating cell growth, and potentially possessing bactericidal or antitumor activity. Overall, α -lactalbumin contributes significantly to the nutritional profile of whey [28, 50].

Table 1. Whey composition

Tabela 1. Skład serwatki

Component:	Content:	Main function(s):
Proteins:		
β -lactoglobulin	3 ÷ 4 g/dm ³	Lowers blood pressure; Enhances appetite; Transports retinol, palmitate, fatty acids, vitamin D and cholesterol; Transfer of passive immune
α -lactalbumin	1.2 ÷ 1.5 g/dm ³	Used in infant food production; Lowers blood pressure; Treatment of chronic stress-induced disease
Bovine serum albumin	0.3 ÷ 0.6 g/dm ³	Fatty acid binding; Cancer prevention; Increase of passive immunity
Immunoglobulins	0.6 ÷ 0.9 g/dm ³	Antivirus activity (HIV); Antifungal and opioid activity
Lactoferrin	0.02 ÷ 0.05 g/dm ³	Antioxidant, antibacterial, antiviral, antifungal, promotes growth of beneficial bacteria
Lactose	45 ÷ 60 g/dm ³	Improves mineral absorption, prebiotic
Vitamins	7.5 mg/dm ³	Antioxidants, enzyme co-factors
Lipids	0.6 ÷ 5 g/dm ³	Sources of energy
Calcium	237 ÷ 560 mg/dm ³	Bone support
Magnesium	63 ÷ 78 mg/dm ³	Enzyme activator

Explanatory notes: Source: author's compilation based on data in [26, 44, 50, 21, 26]

Immunoglobulins (IG) are another critical component of whey, renowned for their immune-supporting properties, antimicrobial and antiviral activities and potential role in reducing blood pressure. Bovine serum albumin (BSA), comprising 5 % of whey protein, inhibits tumor growth and contributes to lipid synthesis. Lactoferrin (LF), a valuable whey protein, plays a pivotal role in iron metabolism stimulation, enhances immune function, exhibits bacteriostatic properties, stabilizes bone tissue and supports cellular growth [50].

Lactose is made up of glucose and galactose. It is the primary carbohydrate found in sweet whey and serves mainly as a nutritional source by improving the absorption of calcium, magnesium and phosphorus in the intestines, as well as facilitating the utilization of vitamin C [41].

Sweet whey contains a spectrum of dairy minerals classified into major and minor categories based on their concentration levels. Major minerals present in significant quantities include calcium, phosphorus, potassium, sodium, chloride and magnesium [30]. Whey is rich in water-soluble vitamins akin to those found in milk, making it an invaluable source of complex B vitamins, particularly riboflavin (B₂) and vitamin B₁₂ [31]. These vitamins play crucial physiological, biochemical and metabolic roles, ensuring normal bodily function. Vitamin B₁₂ deficiency, stemming from genetic factors or inadequate dietary intake (e.g. vegetarian or vegan diets excluding animal products), can lead to anemia, impaired nerve function and compromised fatty acid metabolism [27, 50].

Whey utilization opportunities

The traditional disposal of whey is unsustainable and poses significant environmental risks, resulting in the wastage of valuable nutrients. Producers which view whey as waste have access to four potential utilization options:

1. *Land fertilization.* Whey can be used as a fertilizer, although its application must be carefully managed to avoid adverse effects on soil and plants, particularly influenced by factors such as climate, season and soil composition;
2. *Release into natural water bodies.* This method is prohibited due to whey's high pollution levels, which can severely impact aquatic ecosystems;
3. *Disposal into sewage systems.* This approach is also discouraged as it can overload sewage treatment facilities and pose operational challenges;
4. *Animal feed.* Whey is commonly used as a component of animal feed, providing nutritional benefits [1].

The above-mentioned ways of whey utilization are simple and do not require further processing of whey. Nonetheless, the recent technological developments and ongoing research in the field of whey valorization helped to develop more sophisticated and valuable whey utilization methods, which are mainly represented by usage of

whey-derived products in bakery items, production of whey beverages and different nutritional products [21, 36, 46].

Broadly, there are five primary methods for further utilizing cheese whey. The first method involves the recovery of valuable and functional components, such as lactose and proteins. The second approach utilizes fermentation processes to extract value-added products like lactic acid, butyric acid and butanol. The third option involves employing physicochemical treatments such as coagulation, flocculation, ozonation, thermal and isoelectric precipitation, thermocalcium precipitation, acid precipitation, alkaline precipitation, electrochemical oxidation and alkaline subcritical water gasification [22]. Cheese whey permeate is first acid-fermented to a mixture of volatile-fatty acids; a mixed microbial culture then channels those acids into polyhydroxyalkanoates (PHAs) [6]. Also, the lactose (or proteins) in whey permeate can be chemo-enzymatically converted into polyols – the key “A-side” component of PU formulations. A techno-economic study by Chalermthai et al. modelled an industrial line using inexpensive dairy-waste whey and showed that the resulting bio-polyols could replace petro-polyols in rigid PU insulation foams at a competitive cost [4].

Table 2. Whey-derived product, their usage and functionality

Tabela 2. Produkty pochodzenia serwatkowego, ich zastosowanie i funkcjonalność

Product	Usage and functionality
Whey Butter	Whey butter is produced from whey cream, which is removed from fresh whey in order to decrease volume of fats in proteins
Whey Protein Concentrate (WPC) and Whey Protein Isolate (WPI)	Dried whey is produced after concentration of solids. Whey powder contains 72 ÷ 75 % of lactose, 8 ÷ 9 % minerals and is widely used in production of ice-cream, desserts, cakes, etc. It can replace skim milk powder in dairy production, upgrade quality of meat and fish, can be used in infant formula and pharmaceuticals. It also can be used in production of functional products and production of special clinical food for patients with digestion problems. Whey powder can become a key ingredient in edible film and coating production. Overall whey proteins contribute to functionality of products by increasing aeration in bakery, replacing skim powder in dairy products, improving the quality of meat by emulsifying gelatin, etc.
Lactose	Whey lactose is mainly used in food and pharmaceutical industries. Lactose is used as a sweetener and as a source of fermentable sugars. Lactic acid is a preservative and pH regulator used in food industry. Lactose is widely used in infant food production sector.
Whey beverages	There is a vast number of whey-based beverages. Whey is used in production of probiotic drinks, functional, fermented and flavored drinks.
Bioplastic	With advancement in technology and increasing demand for sustainable packaging, whey valorization techniques advanced and as a result polylactic acid (PLA) and polyhydroxyalkanoates (PHAs) could be produced. PLA and PHA are organic polymers, which can be used in production of edible films.
Bioethanol	Recent advancement also helped to increase the usage of whey as a source of bio-ethanol. Ultrafiltration and reverse osmosis help to increase bioethanol yield, which makes it an attractive source of energy.

Explanatory notes: Source: author’s compilation based on data in [12, 34, 47]

When no higher-value outlet is available, dairies often tanker residual whey or permeate to anaerobic digesters. Under mesophilic conditions (35 °C) the stream's high chemical-oxygen demand ($60 \div 80 \text{ g/dm}^3$) yields about $0.30 \div 0.35 \text{ m}^3 \text{ CH}_4 \text{ kg}^{-1}$ COD removed, supplying on-site combined heat-and-power or upgradable grid bio-methane [11]. The table 2 summarizes list of products which could be derived from whey.

Contemporary whey valorization European Union approaches

The European Union is one of the leading regions which aim at the promotion of sustainable development practices. The New Waste Framework Directive prescribes how waste should be treated focusing on waste recycling. According to the Directive, whey is considered as a resource, meaning that EU producers are expected to change the treatment of whey as mere waste [10]. Experience from the European Union shows that cheese-whey can be moved steadily up the waste-hierarchy – from the by-product status, through material recycling, to energy-and-nutrient recovery.

European dairies first seek to retain the by-product status under the Feed Hygiene Regulation. For example, liquid-feeding data indicate that whey recycling is already widely used across northern Europe. More than 60 % of finishing pigs in Denmark and Sweden and about 70 % in France receive liquid diets in which fresh cheese whey supplies readily fermentable lactose and high-quality protein [9]. In Italy, the Prosciutto di Parma disciplinary goes further, legally requiring heavy pigs to be finished on local Parmigiano-Reggiano whey, embedding by-product reuse in a protected-origin value chain [7].

Under Council Directive 91/271/EEC on urban waste-water treatment, EU dairies may not discharge untreated whey to surface waters [8]. Instead, they pre-treat the effluent or integrate it into on-site biogas plants. Glanbia's Ballyragget facility (Ireland) co-digests whey and process water, producing ~15 GWh of biogas each year [35], while Arla Foods' Nr. Vium dairy (Denmark) routes surplus permeate to a 980 kW anaerobic digester linked to a combined heat-and-power unit [37].

Waste-activated sludge from dairy wastewater ($2 \div 5 \text{ \% P}$, $3 \div 5 \text{ \% N d.m.}$) is now upgraded rather than land-spread. Several plants in Ireland, Portugal and Poland precipitate struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) from digester centrate, capturing up to 90 % phosphorus and 70 % ammonium [32, 45]. The resulting granules comply with Regulation (EU) 2019/1009 and can be marketed as fertilizers [25, 42].

This study aims to address the following research objectives:

- To review international practices and technologies for whey valorization within circular economy frameworks, including food, energy and material recovery pathways;

- To assess the current state of whey utilization and waste handling among selected dairy producers in the Issyk-Kul region of Kyrgyzstan;
- To identify practical and context-specific opportunities and barriers for implementing circular economy business models in the Kyrgyz dairy enterprises.

By thoroughly examining current research on CEBM, cheese whey valorization opportunities and the processing of cheese whey in Kyrgyzstan, this study seeks to enhance existing knowledge and offer evidence-based suggestions for policymakers and researchers in the dairy processing field. The primary objective is to reduce the environmental impact of whey and transform waste into valuable products, thereby creating an additional income source for companies.

Materials and methods

The study employed a combination of literature review and qualitative case-study methods. The literature review aimed to gather and analyze international best practices and technological advancements for whey valorization within circular economy frameworks. In addition, a case-study approach was used to gain an in-depth understanding of whey valorization practices among dairy processing companies in Kyrgyzstan, specifically in the Issyk-Kul region.

For the literature review, various academic and industry sources, including peer-reviewed articles, international reports and regulatory frameworks, were analyzed. Relevant scientific databases such as Scopus, Web of Science and Google Scholar were accessed to find articles published primarily within the last 15 years. Key search terms included "whey valorization", "circular economy", "whey-based products", "whey protein concentrate", "whey processing technologies" and related phrases. The review concentrated on identifying efficient and innovative methods for whey valorization and understanding circular economy implementation, particularly emphasizing practices and regulatory frameworks from European countries due to their advanced application of circular economy principles.

The second part of the study was based on a case-study approach. The case study was conducted in the northern part of the Issyk-Kul region, which is located in the northwest part of Kyrgyzstan. The Issyk-Kul region generates 12 % of GDP of the country and produces 25 % of total industrial production of the country [19]. At the same time, the region is the main tourist location, as Issyk-Kul is the biggest lake of the country, which has a lot of resorts around the lake. Therefore, it is crucial to understand opportunities for whey valorization in the region. The second criteria is production capacity. Each plant processes significant volumes of milk daily and generates large amounts of whey. The third criteria applied was the willingness to participate. The selected companies expressed their readiness to collaborate and provide access for interviews and site visits.

Between May and June 2023, several visits were conducted at three milk processing companies. Interviews were held with the Heads of the production departments or Plant Directors during each visit. On average, each site visit and interview lasted approximately 90 minutes. Although interview questions were prepared in advance, they were adapted and structured differently for each factory due to the unique characteristics of each establishment.

The interviews were structured into three main sections. The first section focused on the company's history, main products and production capacity. The second part delved into whey production and its current utilization within the company. The third section explored questions related to whey recycling opportunities and the company's overall stance on transitioning to a circular economy.

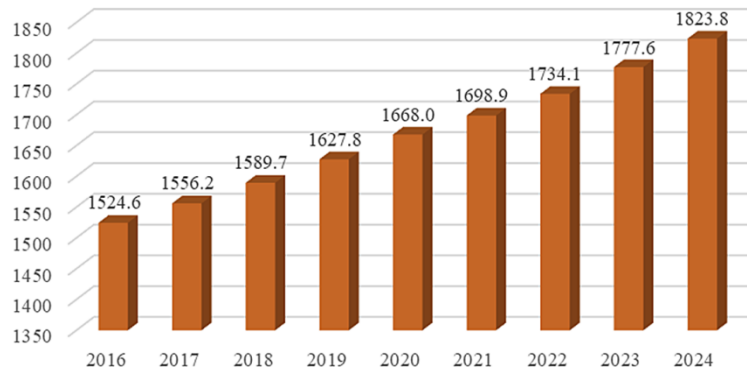
Interview guides were tailored slightly to account for the unique characteristics of each enterprise, ensuring relevance and comprehensiveness of collected data. Interview notes were systematically recorded and content analysis was used to identify common themes, barriers and opportunities related to whey valorization.

The study has several limitations. The sample is limited to three dairy plants in one region and does not capture the full geographic or operational diversity of the Kyrgyz dairy sector. The findings are qualitative in nature and should be interpreted as exploratory rather than generalizable. Furthermore, due to the sensitive nature of financial data, detailed cost analyses of whey valorization were not feasible. Nevertheless, this study offers the first contextual assessment of whey handling and valorization potential in Kyrgyzstan, and provides practical insights that may inform future policy development and sectoral investment strategies.

Results and discussion

General outlook on dairy industry of Kyrgyzstan

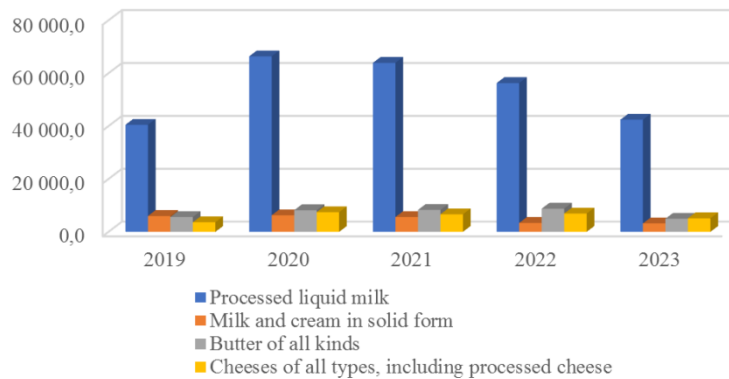
The Kyrgyz Republic is a land-locked small country located in the heart of Central Asia. According to the National statistics committee, the annual demand for milk and dairy products is c. 889,300 tons in terms of milk [11]. Milk production is steadily increasing, as indicated in the figure below. In 2021, the country's total dairy production amounted to around USD 142 million. There are 32 operating dairy productions in the country [23]. According to the National Statistical Committee of Kyrgyzstan, milk production is projected to reach 1.8 million tons in 2024 [19].



Explanatory notes: Source: Author's compilation based on data from the National Statistical Committee of the Kyrgyz Republic [29]

Figure 2. Annual milk production in Kyrgyzstan, 2016÷2024 [tons]
Rycina 2. Roczna produkcja mleka w Kirgistanie w latach 2016÷2024 [tony]

The main output of the dairy industry is processed liquid milk, which totaled 42,404.4 tons in 2023. Cheese production for the same year reached 5,132.2 tons, a 25 % decrease compared to 2022 [36] Cheese serves as a major export dairy item, predominantly shipped to Kazakhstan (9.8 % of total export value) and Russia (89.9 % of total export value) [48]. In 2024, the export value amounted to 33.3 thousand tons of milk and milk products [18].

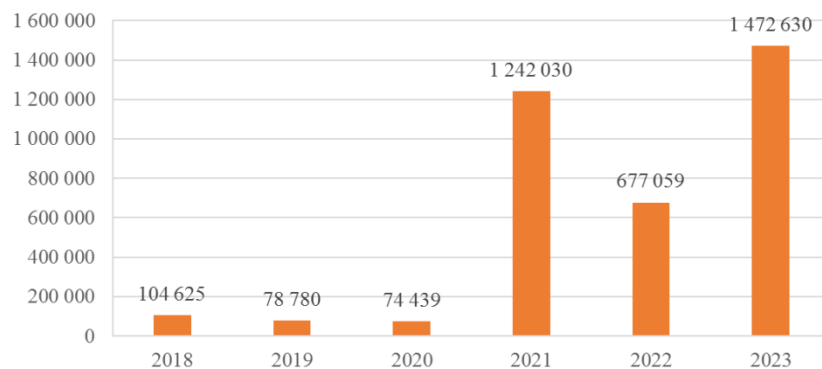


Explanatory notes: Source: Author's compilation based on data from the National Statistical Committee of the Kyrgyz Republic [19]

Figure 3. Milk and dairy products production in Kyrgyzstan, 2017÷2023 [kg]
Rycina 3. Produkcja mleka i przetworów mlecznych w Kirgistanie w latach 2017÷2023 [kg]

The main exporting countries of dairy products are Russia and Kazakhstan. According to the official statistics, in 2021 the volume of exported milk and dairy products to Kazakhstan equaled 25.1 million KGS (c. USD 300,000) and to Russia – 23.3 million KGS (c. USD 280,000) [36].

Import data from the World Bank's WITS portal confirm that Kyrgyzstan is buying more and more whey powder from abroad. In the period of three years before the pandemic (2018 ÷ 2020), imports hovered around 75 ÷ 105 tons, but they jumped to 1.24 thousand tons in 2021, slipped to 0.68 thousand tons in 2022, and then set a new record of 1,472 tons in 2023. Company managers interviewed for this study said demand for whey powder keeps rising; however, because local plants do little, whey processing and production costs here are still high, most of the powder is purchased overseas.



Explanatory notes: Source: Author's compilation based on data from the National Statistical Committee of the Kyrgyz Republic [20]

Figure 4. Import of whey & modified whey, concentrated or not into the Kyrgyz Republic [kg]

Rycina 4. Import serwatki i serwatki modyfikowanej, zagęszczonej lub nie, do Republiki Kirgiskiej [kg]

Company profiles of dairy processors in the Issyk-Kul region, Kyrgyzstan

Ak-Jalga CJSC is one of the oldest dairy processing companies in Kyrgyzstan, established in 1968 and retained after the collapse of the Soviet Union. Located on the southern shore of Issyk-Kul, the plant has a maximum milk processing capacity of 100 tons per day. During summer, the plant processes 90 tons of milk, which decreases to 25 tons in winter. Ak-Jalga produces 11 types of cheese, 3 types of kefir, 2 types of butter, cottage cheese and 3 types of soft cheese. As for production, 60 % is exported to the Russian Federation, 25 % to Kazakhstan, and only 15 % is sold within Kyrgyzstan. Raw milk is sourced from local farmers.

The company offers a diverse range of cheeses, with maturation periods ranging from 45 to 365 days. On average, the plant produces 5 tons of cheese per day. Currently, the company utilizes whey in two ways: as animal feed and for irrigation water after several purification steps. Despite the company's intention to sell whey for further processing, a major challenge lies in logistical issues associated with transporting large volumes of this by-product. The plant has considered purchasing a vacuum evaporator for drying to process and valorize whey; however, due to the high cost of the equipment, the project is currently under consideration by management.

Sut Bulak CJSC is the second-largest dairy producer in the Issyk-Kul region, specializing in cheese production sold under the Dairy Spring brand. Established in 1996 through a joint agreement between Kyrgyzstan and Switzerland, Sut Bulak is part of Spielhofer Swiss Cheese SA, a family business now managed by second-generation cheesemakers Cedric and Florian Spielhofer. The company's competitive advantage lies in Swiss cheese technology and the high quality of its products. Due to financial constraints and limited investment opportunities, the company does not further process cheese whey. Instead, it is utilized as animal feed and for irrigation water after several purification steps. The management of the company is interested in exploring proper whey utilization, but unfortunately, its capacities for whey processing are limited.

Ak Bulak Plus LLC is the third-largest dairy company in the Issyk-Kul region, located in Karakol city. The company produces butter, cheese and whey powder. During the year, the maximum milk processing capacity reaches 80 tons per day, with an average daily processing of 30 tons. The company's products are highly sought after not only in the Kyrgyz Republic, but also in neighboring countries. They are exported to Kazakhstan, Uzbekistan, Tajikistan and major cities in Russia, making up 65 % of the total production volume, while 35 % are sold on the Kyrgyz market.

Ak Bulak Plus LLC stands out among the three companies studied as the only one to have installed brand-new equipment for producing whey powder. In 2022, the company invested in and installed new European cheese production equipment capable of processing up to 10 tons of milk per day. On average, the plant processes 40 tons of whey daily, from which it produces 1 ton of whey powder with a shelf life of 1 year [53].

All three producers are considered to be the largest cheese producers in Kyrgyzstan and particularly in the Issyk-Kul region of the country. According to the ranking of local cheese producers, based on contributions to the country budget for 2019, CJSC Ak Jalga is the leader. The company contributed more than 16 million Kyrgyz soms (c. USD 235,000). The second-largest contributor to the budget was Sut Bulak JSC. Ak Bulak Plus LLC was on the fifth place among 17 cheese producers [40].

According to the company, whey powder serves multiple purposes in the dairy industry, including standardizing milk solids and supplying local confectionery facto-

ries. Currently, Ak Bulak Plus LLC views whey powder as the most economically viable whey-based product, considering other whey products to have shorter shelf lives that make them less feasible for processing options.

Table 3. Calculation of volume of whey production
Tabela 3. Obliczenie objętości produkcji serwatki

	Ak-Jalga CJSC	Sut Bulak CJSC	Ak Bulak Plus LLC
Volume of milk processed/day, tons	90	55	up to 80
Volume of whey production/day, tons	72	44	40
Possible volume of whey powder production, tons	1	0.5	1

Explanatory notes: Source: authors' own data (2023 field measurements)

Three interviews showed that dairy processing companies are interested in whey utilization, however, due to limited access to financing, two of three biggest companies do not process whey at its maximum capacity. Taken together, the three plants generate about 156 tons/day of liquid whey, yet only Ak Bulak Plus dries ≈ 1 ton/day into powder, leaving > 95 % of the stream under-utilized as low-value cattle feed or irrigation water.

Across the EU and North America, three valorization routes dominate, which are protein/lactose fractionation into WPC-35, WPI and edible lactose; fermentative conversion to ethanol, lactic acid and polyhydroxyalkanoate (PHA) bioplastics; and energy-plus-nutrient recovery via anaerobic digestion with struvite precipitation. These pathways supply, respectively, food, material and energy loops within a circular-economy framework, and serve as reference points for assessing the Issyk-Kul plants.

The interviewees converged on three viable CEBMs:

- (a) a hub-and-spoke collection scheme in which Ak Bulak Plus purchases raw whey and shares drying capacity;
- (b) modular membrane equipment ($\leq 10 \text{ m}^3 \text{ h}^{-1}$) leased on a pay-per-liter basis;
- (c) a manure-plus-whey co-digestion plant supplying CHP heat back to cheesemakers.

During the interview, all three studied plants pointed out that there are considerable barriers which hinder opportunities for whey valorization. The main barriers are outlined in the Table 4.

Table 4. Key barriers to whey valorization in Kyrgyz dairies and practical ways to overcome them
 Tabela 4. Główne bariery w zakresie waloryzacji serwatki w kirgiskich mleczarniach i praktyczne sposoby ich pokonania

Current barrier	Proposed actions to overcome barriers
Limited access to capital Sophisticated whey valorization equipment requires high investments, loans are issued at high interest rates	Government support on finance or leasing models for dairy by-product equipment at low interest rates
Seasonal, scattered milk supply Mountain geography and seasonality of milk production coupled with distance between plants (80-150 km apart) makes collection of whey difficult.	Need for hub-and-spoke collection or mobile concentration units to smooth seasonality and distance.
Logistics & cold-chain gaps Few chilled tankers; roads to Issyk-Kul alpine valleys often closed in winter.	Investment in insulated tankers or on-farm chilling to prevent souring during transportation.
Regulatory vacuum No Kyrgyz standard for WPC/WPI; end-of-waste criteria undefined; zero feed-in tariff for biogas.	Adopt or adapt EAEU/GOST standards and introduce pilot feed-in or nutrient-credit schemes.
Underdeveloped technical-service market Limited number of no local agents for membrane, spray-dry or biogas gear; spare parts must be imported.	Supplier incubator or training programs for local engineering SMEs.

Explanatory notes: Source: authors' own data

Conclusions

1. Amid escalating concerns regarding climate change and burgeoning environmental issues, the adoption of CEBM is increasingly recognized for ensuring the enduring preservation of the environment for future generations. Existing research on various circular economy business models underscores the fact that innovating business models are a pivotal determinant not only in decreasing negative impacts on the environment, but also in enhancing a company's competitive edge. Despite encountering numerous obstacles in the development of CEBM, empirical evidence reveals instances of successful businesses operating within sustainable and circular paradigms.
2. Successful plants in the EU and North America now follow three well-proven tracks. They turn whey into food ingredients (whey-protein concentrate, isolate and edible lactose), into new materials and chemicals (ethanol, lactic acid, polyhydroxyalkanoate bioplastics) and into energy plus fertilizer (biogas with phosphorus recovery as struvite). These cases show that whey is not mere waste, but can be a profit center. But a key determinant of such success is appropriate government.

3. The three dairies surveyed together create about 156 tons of liquid whey every day, yet only one of them dries roughly 1 ton/day into powder; the rest goes to cattle feed or ends up as treated effluent. At the same time Kyrgyzstan's imports of whey powder jumped from c. 90 tons in 2020 to 1,472 tons in 2023, proving that a home market already exists but is supplied from abroad.
 - Surveyed managers outlined three CEBMs they believe could work:
 - A *hub-and-spoke* scheme in which Ak Bulak Plus toll-dries whey collected from nearby plants;
 - *Leased membrane skids* that let each dairy concentrate proteins on-site and cut transport loads;
 - *Co-digestion* of whey with manure to make biogas and struvite fertilizer.
4. The biggest barriers are high start-up costs, scattered and seasonal milk supply, weak cold-chain logistics and the lack of national standards or incentives for whey products and biomethane. Low-interest leasing, insulated tankers and rapid adoption of EAEU/GOST whey standards, as well as a pilot feed-in tariff would remove most of these hurdles and keep the growing whey-powder market (now worth USD 3–4 million per year) inside the Kyrgyz economy.

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MOŻLIWOŚCI WALORYZACJI SERWATKI W KIRGISTANIE: ZASTOSOWANIE PRAKTYK GOSPODARKI O OBIEGU ZAMKNIĘTYM

Streszczenie

Wprowadzenie. Serwatka serowa jest głównym produktem ubocznym przetwórstwa mleczarskiego i nadal jest wyrzucana jako odpad w wielu krajach, w tym w Kirgistanie. Zawiera ona jednak wysokowartościowe białko, laktozę, minerały i substancje bioaktywne, które można odzyskać dzięki modelom biznesowym gospodarki o obiegu zamkniętym (CEBM) i przekształcić w składniki żywności, biomateriały lub energię. Serwatkę można w pełni wykorzystać na trzech płaszczyznach gospodarki o obiegu zamkniętym, takich jak odzysk składników żywności (koncentrat/izolat białka serwatkowego i laktoza spożywcza), konwersja materiału na etanol, kwas mlekowy, bioplastyki polihydroksyalkanianowe i poliole poliuretanowe oraz odzysk energii i składników odżywczych poprzez fermentację beztlenową, a następnie produkcję nawozu struwitowego. Przeprowadzono jakościowe studium przypadku w trzech największych zakładach mleczarskich w regionie Issyk-Kul. Audyty na miejscu i wywiady półustrukturyzowane pozwoliły na zmapowanie ilości serwatki, obecnych tras utylizacji oraz opinii kierowników na temat waloryzacji.

Wyniki i wnioski. Zakłady łącznie wytwarzają około 156 ton płynnej serwatki dziennie, ale tylko jedna instalacja rozpyłowo suszy około 1 tonę dziennie do postaci proszku. Pozostała część jest wykorzystywana jako pasza dla zwierząt o niskiej wartości lub odprowadzana po minimalnym przetworzeniu. Krajowy popyt na serwatkę przetworzoną rośnie jednak: import serwatki w proszku wzrósł z 0,09 kt w 2020 r. do 1,47 kt w 2023 r. Respondenci wskazali trzy technicznie wykonalne systemy CEBM: system suszenia w układzie piasta-ramię, dzierżawiony sprzęt membranowy do zagęszczania serwatki na miejscu oraz współfermentację obornika i serwatki w celu uzyskania biogazu i nawozu struwitowego. Przeszkody w waloryzacji serwatki odzwierciedlają bariery globalne, w tym niewystarczające inwestycje, brak wsparcia ze strony kadry zarządzającej, brak regulacji rządowych, sezonowość i rozproszenie dostaw mleka, słaba logistyka łańcucha chłodniczego oraz niedobór innowacji technologicznych.

Słowa kluczowe: waloryzacja serwatki, modele biznesowe gospodarki o obiegu zamkniętym, Kirgistan, przetwórstwo mleczarskie, produkty uboczne przemysłu mleczarskiego 