CHEMICAL ENGINEERING TRANSACTIONS

VOL. 103, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Panos Seferlis, Yee Van Fan, Athanasios Papadopoulos

ISBN 979-12-81206-02-1; **ISSN** 2283-9216

DOI: 10.3303/CET23103003

Implementation of Circular Economy in the Water Sector in the Industrial Region of Kazakhstan

Ivan Radelyuk[a,*], Jiří Jaromír Klemeš[b], Xuexiu Jia[b], Madeniyet Yelubay[a]

[a]Department of Chemistry and Chemical Technology, Toraighyrov University, Pavlodar 140000, Kazakhstan
[b]Sustainable Process Integration Laboratory (SPIL), NETME CENTRE, Faculty of Mechanical Engineering, Brno University of Technology – VUT Brno, Technická 2896/2, 616 69, Brno, Czech Republic
radelyuk.i@tou.edu.kz

The water sector has been considered as the priority in implementing the Circular Economy (CE) in Kazakhstan, aiming to reduce anthropogenic pressure on the environment and promote efficient water resource use. Challenges have been rising significantly in the water sector in Kazakhstan, while tailor-made research on the CE in the water sector has not been addressed. This study assesses the water management system in different sectors of the economy of the Pavlodar region of Kazakhstan, focusing on (waste)water distribution networks, irrational water use, emissions, and associated water and energy losses. Interviews were conducted with stakeholders from local industries, governmental bodies, water supply utilities, and academia to understand their willingness to adopt the CE principles. Responses from the interview were examined using the SWOT (Strengths, Weaknesses, Opportunities, and Threats) and the Analytic Hierarchy Process (AHP) approaches. The existing water infrastructure is recognised as a prominent strength and a crucial factor for the prospects of CE implementation. The inadequate and outdated state of the water infrastructure, along with substantial water losses, are recognised as highly influential weaknesses in the industrial water management systems of the region, which were also acknowledged as the weakest aspects and obstacles towards the implementation of the CE principles in the water sector. High investment costs for water infrastructure modernisation and the projected increase in water consumption were considered major threats to the successful implementation of CE practices in the studied region.

1. Introduction

The shortage of available freshwater resources is alarming worldwide with the rising water scarcity risks in the nearest future (Jia et al., 2020). Natural and anthropogenic factors, such as climate change, population growth, and increasing rate of water quality degradation, have been aggravating the issues and require prompt actions. Consideration of water as a resource managed by multiple “nature-managed” and “human-managed” interactions refers to the concept of Sustainable Water Use (SWU) (Radelyuk et al., 2023). Three dimensions of sustainability have to be taken into account equally: The environmental dimension, indicating minimum water withdrawal and maximum water pollution reduction; the economic dimension, which ensures water is available for the general public and brings profits from its usage in the form of saved cost; and social dimension, which are associated with the equal and responsible access to safe and available water. It is important to identify and maintain the balance between environmental resilience and socio-economic activities.

The adequate response for achieving the SWU involves the implementation of Circular Economy (CE) principles in the water sector. CE is a concept that promotes shifting from a linear to a circular model of resource use with rooted “4Rs” (“reduction, reuse, recycling, and recovery”) principles. Water, as one of the most limited resources worldwide, is also under special consideration of the CE principles (Morseletto et al., 2022). The expected outcomes of CE implementation include, firstly, alleviation of the stress on freshwater supply by water reuse and adoption of water-saving technologies; secondly, elimination of water and energy losses due to ineffective water delivery systems; thirdly, the potential for resources recovery and decreasing pressure on the extraction of new resources; and finally, special attention is paid on safe utilisation of potentially toxic substances without their direct release into the environment.

Paper Received: 17 March 2023; Revised: 05 July 2023; Accepted: 19 July 2023
Please cite this article as: Radelyuk I., Klemeš J.J., Jia X., Yelubay M., 2023, Implementation of Circular Economy in the Water Sector in the Industrial Region of Kazakhstan, Chemical Engineering Transactions, 103, 13-18 DOI:10.3303/CET23103003

Kazakhstan released the national program for a transition towards a “Green Economy” with the implementation of the CE principles in 2013 (President, 2013). Water issues have been accepted as the priority direction in the implementation of the CE in the respected national program (Government, 2020).
Kazakhstan exhibits moderate water stress with known mismanagement problems in the water sector. According to Karatayev et al. (2017), Kazakhstan is facing the risk of future water scarcity, significant water losses due to the obsolete infrastructure of water facilities, and damaging pollution of natural water sources. Moreover, the impact of Climate Change, increase in water demand, weakness in the implementation of institutional measures, and uncontrolled use of water resources by upstream neighbourhoods only jeopardise the situation.Industries are the major water consumers that are under special consideration for the adoption of the SWU and CE principles. The Pavlodar region is one of the largest industrial centres in Kazakhstan. Metallurgical, chemical, and petrochemical industrial activities have been causing environmental issues to the water resources in this region (Radelyuk et al., 2021). The water usage practices of these massive industrial clusters are worth receiving significant attention. According to the Bulletin of National Statistics (2022), the water supply for the industries in the city was over 53.5×10^6 m^3 in 2021, taking more than 68 % of the total water supply in the city. At the same time, 15.7 % of the water loss was registered, and 31×10^6 m^3 was received by wastewater treatment stations in the whole city. The manufacturing and energy sectors have been listed as the top water consumers in the region (Chuah et al., 2021).There is an urgent need to investigate water management strategies aiming to achieve a minimal water footprint by decreasing the emissions into the natural water sources, reducing freshwater abstraction, and the reduction of energy consumption. As an initial step, it is crucial to gain a comprehensive understanding of the perceptions held by key stakeholders towards these changes. To achieve this purpose, this work is designed to reveal the impact factors which can potentially facilitate the adoption of the Circular Economy concept in the water sector in the industrial enterprises in the Pavlodar region of Kazakhstan.

2. Methodology

This work was performed following these five steps: (i) Identification and selection of stakeholders for the interviews and design of the questionnaires; (ii) Visits and semi-structured “on-site” interviews with selected stakeholders; (iii) Arrangement and extraction of the SWOT factors based on the responses from the interviews carried out; (iv) Distributing the questionnaire with the identified SWOT factors among the stakeholders for quantitative evaluation of the state-of-the-art of the water management and water use systems in the region using a pair-wise comparison between factors inside each particular group; and (v) Analysis of the obtained results using Analytic Hierarchy Process (AHP) method (Razak et al., 2022).
The following key stakeholders were selected for the interviews, which provide the “first-hand information” data and dissemination of the developed questionnaire: (i) key engineers who are responsible for water supply and water use in the industries, including oil and gas refining companies (including one of the three oil refineries in Kazakhstan), energy utility companies, metallurgy enterprises (including the only aluminium smelter in Kazakhstan); (ii) representatives from the government, including municipal employees from the departments responsible for the environmental regulation, water resources management, and utility management of the region; (iii) representatives from the water supply and water discharge operating companies; and (iv) representatives from academia who train the employees from the water use sector in industry and conduct related research in the field. Unstructured interviews in an in-depth way to understand the current conditions of sectoral water management systems and the willingness of stakeholders, including individuals, businesses, and the government, to accept and implement the rational and sustainable water use principles. The interviews took place during the visits to the enterprises and governmental bodies from September to December 2022. The questions designed for the interviews were dedicated to the following issues: a scheme of water use in the sector, conditions of infrastructure, including pipelines and treatment units, statistics of water losses (including due to damages), access to efficient water-saving techniques, evaluation of the staff competencies, the existence of water-saving potential in the selected sectors, perspectives towards implementation of the CE principles, opinions about water tariffs, drawbacks and advantages of the current water institutes. The SWOT factors were identified during the conversations conducted with each individual organisation. Following the completion of all the visits, the factors were subsequently grouped and formulated into a pairwise comparison questionnaire. The questionnaire was then distributed to stakeholders during the period of January to March 2023. This step was followed by the AHP analysis, which was initially introduced by Saaty (1987), and has been widely applied to providing insights into the relative importance of the identified factors, including in water management. Thus, the final result is supposed to present the most important and influential factors within each SWOT group, which support or obstruct the transition and implementation of the Circular Economy principles in the industrial enterprises of the region.

The results of this study are based on the responses from 14 respondents: two from academia, six from industry, three from water supply companies, and three from governmental bodies. While all the respondents were guaranteed confidentiality of their names and positions, there were potential risks of biased answers from the interviewees due to potential conflicts of interest. Also, one of the largest water consumers in the region (the only enterprise in Kazakhstan to produce alumina and bauxite) declined participation in both interviews and questionnaire filling. Also, the main water supplier responsible for delivering drinking water and managing wastewater for the city refused to participate in interviews but did complete the questionnaire. These facts have been considered as limitations for this study, as the opinions of these stakeholders could have provided valuable insights. However, the majority of stakeholders shared their opinions, which enabled a holistic perspective to be taken when examining the situation.

3. Results and discussions

Table 1 shows the identified and ranked SWOT factors. The average value of consistency ratios is 0.13, which is close to the recommended value of 0.1. However, the relevance of this parameter has been argued because the pair-wise comparisons are based on the subjective opinions of the respondents (Gómez-Limón and Atance, 2004)

Table 1: Identified SWOT factors (alphabetically, ranked using the AHP)

SWOT factors		Rank (%)
Strengths		
(S1)	Availability of water infrastructure	1st (18)
(S2)	Availability of water resources in the region	4th (17)
(S3)	Existence of flowmeter networks for efficient water consumption metering	2nd (18)
(S4)	Existence of regulatory standards and legislative framework	6th (13)
(S5)	Influence of government policies on the transition to water-saving technologies and emissions decrease	5th (16)
(S6)	Presence of the circulating water supply systems	3rd (18)
Weaknesses		
(W1)	Impact of the Covid-19 pandemic	6th (12)
(W2)	Lack of research-based solutions \ research in the water use sectors	4th (16)
(W3)	Lack of competencies with the employee on places \ Lack of employee	3rd (17)
(W4)	Poor \ obsolete conditions of the water infrastructure	1st (21)
(W5)	Significant water losses	2nd (19)
(W6)	The current tariffs on water use	5th (15)
Opportunities		
(O1)	Enterprises' plans for transition to advanced methods waste-\reused- waters treatment	2nd (22)
(O2)	Implementation of infrastructure projects (major repairs of existing and building of new infrastructure)	1st (25)
(O3)	Large volume of generated treated wastewater, which is potentially eligible for reuse	4th (19)
(O4)	Opportunities for regeneration of associated resources from wastewater (energy, phosphorus, etc.)	5th (15)
(O5)	Potential for expanding water saving by development and implementation of water reuse schemes	3rd (19)
Threats		
(T1)	Climate change	6th (10)
(T2)	Contamination of water resources	2nd (18)
(T3)	Corruption	4th (15)
(T4)	Increase in water consumption	3rd (17)
(T5)	Influence of associated costs on modernisation	1st (19)
(T6)	Influence of external political factors and force majeure	7th (10)
(T7)	Lack of environmental awareness and related specific knowledge	5th (11)

The attempt to allocate the identified factors among the pillars of sustainability has revealed several trends and interconnections. The Strengths have been distributed across all dimensions, indicating a positive potential for meeting sustainability criteria. Half of the Strengths (S1, S3, S6) are related to economic factors, suggesting ongoing efforts by stakeholders towards water-saving actions. However, it appears that this transition has reached its capacity, as reflected in the even distribution of Weaknesses among the social and economic dimensions. The group of economic Weaknesses (W4, W5, W6) highlights the system's disadvantages and presents obstacles to achieving the goals set by the Government. Social Weaknesses (W1, W2, W3), on the other hand, seem to be influenced more by external factors rather than the industries themselves, but they also require attention to be solved. Opportunity factors are distributed among the environmental and economic dimensions. Economic Opportunities (O1, O2) address the existing Weaknesses and indicate the potential solutions. If these Opportunities are taken seriously and implemented intensively, they can directly contribute to reducing environmental pressure, as reflected in the environmental factors (O3, O4, O5). Existing and potential Threats have been identified across various levels with different levels of importance, highlighting the complexity of the current situation. The Threats appear to be independent of each other, making mitigation challenging and involving multiple stakeholders and actors in pursuit of the established goals.

3.1 Strengths

The respondents were requested to answer the following question: Please, compare in pairs the importance of the factors from the "Strengths" group in the context of the implementation of the principles of water conservation and the "Circular Economy" in your organisation or in the industrial sector in the region? The response results showed that the scores were relatively evenly distributed with the slight prevalence of the factors S1, “Availability of water infrastructure”, S3 “Existence of flowmeter networks for efficient water consumption metering”, and S6 “Presence of the circulating water supply systems”. These factors focus on the technological aspects and readiness of the enterprises for the enhancement of water reuse and decrease in water withdrawal. Several enterprises reported that up to around 60 % of the processed water has already been reused after preliminary treatment. Also, a few enterprises have installed advanced systems of water flowmeters for efficient water use monitoring and identify water losses. Therefore, this parameter is considered of greater importance mainly by respondents from industries and water suppliers. However, almost all the reused water has been sent to cooling towers and evaporated into the atmosphere afterwards. The fact that the region is located near the largest river in Kazakhstan brings the factor S2, “Availability of water resources in the region”, also to the list, as concerns have been shown regarding the future condition of the river water availability and quality.

The other parameters were also considered significant in the context of industrial water use. Factor S5, “Influence of government policies on the transition to water-saving technologies and emissions reduction”, was addressed by the newly updated version of the Ecological Code. It claims and promotes the usage of the Best Available Techniques (BAT) as the core driver to improve the environmental conditions in the mid-term perspective and to shift towards resource use optimisation in the long-term perspective (Kazakhstan, 2021). The related factor S4, “Existence of regulatory standards and legislative framework”, represents a strong normative system of the industries and regulates water use processes for each unit, water supply, and water discharge. These established standards are constantly reviewed (once per five years) considering updated conditions in the technological process of the enterprises and requirements by the government, taking into account quantitative and qualitative characteristics of water use.

3.2 Weaknesses

The following question was asked in the questionnaire: Please, compare in pairs the degree of influence of the factors from the "Weaknesses" group in the context of the (potential) implementation of the principles of water conservation and the "Circular Economy" in your organisation or in the industrial sector in the region? Factors W4, “Poor \ obsolete conditions of the water infrastructure”, and W5 “Significant water losses”, was selected as the most influential factors in the industrial water management systems of the region. Representatives from the industries expressed their concern about the conditions of water infrastructures, particularly of pipelines. The main water pipelines in the region were built in 1960 s-70 s and demand renovation, which is also a cost-intensive procedure. The interviewed practitioners from the industry reported that their capacity to reuse wastewater is limited by the conditions to treat the water to a certain quality level with the existing wastewater treatment schemes. Tough climatic conditions and the impact of groundwater also jeopardise the conditions of the infrastructure and increase the speed of corrosion, which leads to frequent incidents and damage to the pipelines. Thus, these factors seriously weaken the shift towards the implementation of the CE principles in the industry regarding water issues.

The third most important factor reported by the respondents is factor W3 “Lack of competencies with the employee on places / Lack of employee”. This factor was particularly emphasised by water supply companies and governmental bodies, as the sector faces a shortage of qualified staff due to low salaries. Factor W3 is closely followed by factor W2, “Lack of research-based solutions/research in the water use sectors”. Both factors can be considered from the common perspective as a serious lacking of the institutional approach and collaborative transition to the CE in the water sector. For example, multiple government agencies regulate fragmented sectors of water use at different levels, which creates loops in establishing a unified standard to limit environmental emissions and/or maintaining the tariffs for water supply (Karatayev et al., 2017). The obstacles for researchers were expressed in the barriers to providing necessary data for suggesting potential solutions, low interest in the research direction in general, and the shifted major focus on the daily tasks of the researchers.

Factor W6 “The current tariffs of water use”, was rated at the bottom level of the rating. The UN World Water Development Report on “Valuing Water” has blamed governments around the world for their failure to establish a clear value on water (UN, 2021). During the interviews, respondents admitted that the supplied water tariffs are very low for processing needs (0.04 – 0.10 USD per m^3), which slows down the shift to water-saving technologies and enhanced water reuse.
Factor W1, “Impact of the Covid-19 pandemic”, has gained the lowest influential score in comparison with other factors. It has been included in the list as it caused delays in the implementation of some projects for establishing and developing water infrastructure, which led to increasing costs of these projects and waste of time.

3.3 Opportunities

The following question has been asked for this group: Please, compare in pairs the importance of the factors from the "Opportunities" group in the context of the implementation of the principles of water conservation and the "Circular Economy" in your organisation or in the industrial sector in the region? The factors of this group were distributed relatively evenly in most of the responses. In this group, the factor O2 - “Implementation of infrastructure projects (major repairs of existing and building of new infrastructure)” obtained the highest score. Most of the industrial enterprises have reported their plans and emphasised the importance of repairing pipelines, pumps, and other already existing infrastructure, which is supposed to enhance the water-saving efficiency of existing infrastructures. Most of the pipelines were built during the Soviet Era (in the 60s-70s). Nowadays, part of them has been replaced. The process of replacement is slow but permanent. This factor is followed by the related factor O1 “Enterprises’ plans for transition to advanced methods waste-\reused- waters treatment”, with the particular goal of increasing water reuse. An interesting situation was observed in the responses for factors O3, “Large volume of generated treated wastewater, which is potentially eligible for reuse”, and O5 “Potential for expanding of water saving by development and implementation of water reuse schemes”. Some enterprises already reported that they reuse all the possible amounts of treated wastewater from technological units and have excess demand for external wastewater reuse. Other factories, in contrast, generate large volumes of treated wastewater that can be reused but do not have such a large demand for water reuse. These observations provide insights into the potential implementation of eco-industrial parks (Chin et al., 2021) in further projects. The factor O4 “Opportunities for regeneration of associated resources from wastewater (energy, phosphorus, etc.)”, is barely visible by industries and governmental bodies and has been rated as important only by water supply companies.

3.4 Threats

The group “Threats” gained the most of the factors during the interviews. The respondents were suggested to answer the question: Please, compare in pairs the degree of influence of the factors from the "Threats" group in the context of the (potential) implementation of the principles of water conservation and the "Circular Economy" in your organisation or in the industrial sector in the region? The factors T5, “Influence of associated costs on modernisation”, T2 “, Contamination of water resources”, and T4 “Increase in water consumption”, were ranked as the most influential parameters among the group. All these mentioned threats can be fixed by installing modern equipment, which was indicated as the main obstacle for several companies due to its high cost. The delivery of infrastructural projects requires a significant amount of investment, which explains the high score of this factor. The requirements of the updated Ecological Code prevail over the unwillingness of the business to invest in modernisation and demand it. The population is predicted to increase in the studied region as well as along the whole river basin, which will lead to an increase in water consumption. Coupled with environmental threats by the industries (already presented in detail by Radelyuk et al. (2023)), these challenges can cause higher pressure on the River in the mid-and long-term.
Other factors have also been pointed out by the respondents and may have influenced other factors. The factor T3, “Corruption”, was addressed considering that industries have the potential to influence law-making and establish the standards for environmental emissions. It is also reflected in the factor T7, “Lack of ecological awareness and related specific knowledge”. On a retrospective scale, businesses in Kazakhstan should be further improved in raising ecological awareness, which can reduce the generation of environmental issues.
The respondents admitted the vulnerability to factor T6, “Influence of external political factors and force majeure”. The Covid-19 pandemic, the Russian invasion of Ukraine, related risks of sanctions, and other force majeure may have affected the established supply chains, manufacturing processes, delayed the implementation of the projects and improvement of the infrastructure, etc. It is interesting to see that factor T1, “Climate Change”, is barely considered as influential on the transition towards the Circular Economy in the industrial water use in the region, which is reflected in its ranking at the bottom of the list.

4. Conclusions

The SWOT-AHP method was used to assess perspectives for the implementation of the Circular Economy concept in the water sector in the Pavlodar Region of Kazakhstan with a focus on the industries. “On-site” interviews with key stakeholders have identified the key SWOT factors which should be considered while planning the transition to water-saving and drop-in water pollution activities in this region. The strengths are already available water infrastructure and existing circulating water supply systems. The main challenges are poor conditions of such infrastructure with significant water losses, which can be avoided. The priority for industrial enterprises is to focus on the implementation of infrastructure projects, particularly on major repairs of existing units, including pipelines and wastewater treatment stations. The opportunities for resource regeneration are barely visible and laid out in the plans of the enterprises. Low tariffs, associated costs, and the increase in water consumption are recognised as major threats, which may have an impact on the willingness of the industries to achieve a high level of Circular Economy implementation in water issues in the region.

Acknowledgements

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14972725).
The research is dedicated to the memory of Prof Jiří Jaromír Klemeš - the Head of the Sustainable Process Integration Laboratory – SPIL who was the leading researcher in the area of process integration.

References

Bulletin of National Statistics, 2022, About water supply and water discharge infrastructure in the Pavlodar region. (in Russian), <stat.gov.kz/region/263009/statistical_information/industry/55157>, accessed 17.03.2023.
Chuah L.F., Klemeš J.J., Bokhari A., Asif S., 2021, A Review of Biodiesel Production from Renewable Resources: Chemical Reactions. Chemical Engineering Transactions, 88, 943-948.
Chin H. H., Varbanov P. S., Klemeš J. J., Bandyopadhyay S., 2021, Subsidised water symbiosis of eco-industrial parks: A multi-stage game theory approach. Computers & Chemical Engineering, 155, 107539.
Gómez-Limón J.A., Atance I., 2004, Identification of public objectives related to agricultural sector support. Journal of Policy Modeling, 26(8), 1045-1071.
Government, 2020, On approval of the Action Plan for the implementation of the Concept for the transition of the Republic of Kazakhstan to a "green economy" for 2021 – 2030 (in Russian), Resolution № 479 of the Government of the Republic of Kazakhstan, <adilet.zan.kz/rus/docs/P2000000479>, accessed 17.03.2023.
Jia X., Klemeš J.J., Wan Alwi S.R., Varbanov P.S., 2020, Regional water resources assessment using water scarcity pinch analysis. Resources, Conservation and Recycling, 157, 104749.
Karatayev M., Kapsalyamova Z., Spankulova L., Skakova A., Movkebayeva G., Kongyrbay A., 2017, Priorities and challenges for a sustainable management of water resources in Kazakhstan. Sustainability of Water Quality and Ecology, 9-10, 115-135.
Kazakhstan, 2021, Ecological Code of the Republic of Kazakhstan. (in Russian), <adilet.zan.kz/rus/docs/K2100000400#z4470>, accessed 17.03.2023.
Morseletto P., Mooren C.E., Munaretto S., 2022, Circular economy of water: definition, strategies and challenges. Circular Economy and Sustainability, 2, 1463–1477.
President, 2013, About the Concept for the transition of the Republic of Kazakhstan to a "green economy" (in Russian), Decree № 577 of the President of the Republic of Kazakhstan, <adilet.zan.kz/rus/docs/U1300000577#z1>, accessed 17.03.2023.
Radelyuk I., Naseri-Rad M., Hashemi H., Persson M., Berndtsson R., Yelubay M., Tussupova K., 2021, Assessing data-scarce contaminated groundwater sites surrounding petrochemical industries. Environmental Earth Sciences, 80(9).
Radelyuk I., Klemeš J.J., Tussupova K., 2023, Sustainable Water Use in Industry—Reasons, Challenges, Response of Kazakhstan. Circular Economy and Sustainability, DOI: 10.1007/s43615-023-00269-y.
Razak N.H., Zulkafli N. I., Klemeš J. J., 2022, Analytical Hierarchy Process for Automated Fertigation Blending System in Reducing Nutrient and Water Losses. Chemical Engineering Transactions, 97, 493-498.
Saaty R.W., 1987, The analytic hierarchy process—what it is and how it is used. Mathematical Modelling, 9(3), 161-176.