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Composite Assessment of Innovative Development In Water and Wastewater Enterprises: Digitalization And Climate Neutrality Drivers*

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Abstract

This paper builds on the author's earlier work (Moroz, 2024) and extends the integral indicator of innovative development for water and wastewater enterprises. The extension responds to three challenges now facing the sector: rapid digitalisation, the EU's push towards climate neutrality and tighter regulation. The original seven-component model (resource, technological, personnel, effectiveness, institutional, social and ecological) is supplemented with 26 new indicators drawn from the IWA performance measurement framework, the European Benchmarking Co-operation and the OECD methodology for composite indicators. Among the additions are digital transformation metrics, energy and climate indicators (unit energy consumption, carbon footprint, energy self-sufficiency at treatment plants) and service quality metrics that can be measured directly (supply continuity, affordability, network coverage under SDG 6) — replacing health-based proxies whose link to any single utility is hard to establish. The paper also discusses the critical infrastructure status of water utilities and what it means under the NIS2 Directive and the revised EU wastewater directive (Directive (EU) 2024/3019), which requires treatment plants to reach energy neutrality by 2045.

Keywords: innovative development; integral indicator; water supply and wastewater treatment; digitalisation.

Introduction

Water and wastewater utilities provide services that no modern society can do without. Yet in Poland, most of these enterprises have been slow to innovate, and the consequences are visible: ageing infrastructure, high energy costs and growing regulatory pressure.

Fixed assets are wearing out, technology lags behind what is available, and there is an urgent need for solutions that save energy, protect the environment and improve service quality. All of this calls for faster innovative development — and faster development requires a reliable way of measuring where each enterprise stands.

One practical step is to improve how innovation is assessed. The digital transformation of the water sector, documented by Daniel et al (2023) across 64 utilities in 28 countries, is now a major driver of change. At the same time, the revised EU urban wastewater directive (Directive (EU) 2024/3019) sets a deadline of 2045 for treatment plants to become energy-neutral. Energy indicators can therefore no longer be left out of any serious innovation assessment.

The academic discussion around innovation measurement has grown considerably. Researchers, regulators and enterprise managers all face the same basic questions: is innovation actually happening? How much? And can we talk about 'innovative development' if the innovations adopted have made environmental problems worse?

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Composite indicators — single numbers that summarise a complex picture — have a long track record in this area. At the enterprise level, a number of scholars have tackled the problem. Heiets' and Semynozhenko (2006), Maliuta (2011), Illiashenko (2013), Kariuk (2012), Kuzhda (2008), Chervan'ov (1999), Nejkova (1990), Yastrems'ka and Blyzniuk (2008), Prokhorova and Mushnykova (2014) and Lapko (2005) all proposed methods for measuring innovation in engineering, energy, construction and agriculture.

The Ukrainian school is particularly notable: Maliuta (2011) used four components, Illiashenko (2013) worked with technological, marketing, organisational and personnel dimensions using additive aggregation, and Prokhorova and Mushnykova (2014) built a five-component model with min-max normalisation.

Natividade et al (2021) took a different route, proposing a composite index for intrapreneurial orientation in SMEs that uses the Choquet integral instead of simple additive aggregation — an approach that avoids the full compensability problem described in the OECD Handbook (Nardo et al, 2008). None of these models, however, combines ecological, social and institutional dimensions, and none was designed for the water and wastewater sector, where environmental and social outcomes are central to the business itself.

The result is a clear gap: innovation in water and wastewater enterprises remains under-measured. Rating systems and indices exist, but they tend to focus on operational efficiency rather than on the innovation process as a whole.

At the international level, the Oslo Manual (OECD/Eurostat, 2018) provides a common framework for collecting and reporting innovation data across all industries. Its fourth edition broadened the definition to include process, organisational and marketing innovations — all relevant to the water sector, where new technology often goes hand in hand with changes in how services are managed.

The OECD/JRC Handbook on Constructing Composite Indicators (Nardo et al, 2008) sets out a ten-step methodology covering everything from variable selection and normalisation to weighting, aggregation and sensitivity analysis. It remains the main reference for anyone building this type of indicator.

Kiparsky et al (2013) argued that the water sector suffers from an 'innovation deficit' rooted not in technology but in institutional and organisational barriers. Path dependencies between technology and institutional structures, they showed, slow down the uptake of new solutions. This finding supports the inclusion of an institutional component in the model proposed here.

The IWA Performance Indicator System (Alegre et al, 2016), now in its third edition, offers more than 170 indicators grouped into six areas: water resources, personnel, physical assets, operations, service quality and finance. It is used by regulators across Western Europe, including Ofwat in the UK and ARERA in Italy. But it measures how well a utility operates, not how innovative it is — and that is the gap this paper addresses.

Digitalisation is attracting growing attention. Daniel et al (2023) found that the distribution network is typically where utilities start their digital journey. Grigg (2025) reviewed the full range of digital tools now available: SCADA, digital twins, process optimisation. Both studies make the case for including digitalisation in any up-to-date innovation assessment.

The shift towards sustainability and the circular economy (Obaideen et al, 2022; Kehrein et al, 2020) means that indicators must now also capture resource recovery, energy self-sufficiency and carbon footprint reduction. The European Benchmarking Co-operation (EBC, 2024) already evaluates utilities on water quality, reliability, service, sustainability and finance.

Other relevant contributions come from Berg (2020) on benchmarking methods, Marques and Simões (2020) on the importance of including service quality, Cetrulo et al (2019) on the lack of ecological and social indicators in developing-country studies, and Vilarinho et al (2024), who proposed the Water Utility Service Quality Index based on the World Bank's 'Utility of the Future' framework. Sakai (2024) called for future research to address the social and environmental context, ageing infrastructure and climate neutrality. Goh and See (2021), reviewing twenty years of water benchmarking literature, found that innovation indicators simply do not appear — confirming the gap this paper sets out to fill.

Water and wastewater enterprises are not just ordinary businesses. Under Polish law (Act of 26 April 2007 on Crisis Management), the water supply system is classified as critical infrastructure. A planned amendment transposing the EU CER Directive (Directive (EU) 2022/2557) will extend this classification to wastewater systems as well. The NIS2 Directive (Directive (EU) 2022/2555) adds cybersecurity obligations for water utilities.

All of this raises the stakes: measuring innovation in these enterprises is not only an economic question but also a matter of national security.

The aim of this paper is to extend the integral indicator of innovative development for water and wastewater enterprises by adding digitalisation and climate-neutrality dimensions, while keeping the ecological, social and institutional specifics that make this sector different. The extended indicator set draws on: (1) the IWA system (Alegre et al, 2016), notably Op25, Op31 and Op39; (2) the digital transformation survey of Daniel et al (2023); (3) the network failure classification of Kwietniewski and Rak (2010); (4) energy data from Masłoń et al (2024) and Czekała (2023); and (5) the Oslo Manual (OECD/Eurostat, 2018) and the OECD Handbook (Nardo et al, 2008) for normalisation, weighting and aggregation.

Research Results

Water and wastewater enterprises differ from firms in other sectors in several important ways. They provide services essential to public health and daily life. The quality of those services affects not only health outcomes but also household budgets, social cohesion and broader living standards. Any assessment of their innovative development must therefore include a social component.

Water resources both define the core activity of these enterprises and reflect the environmental consequences of their operations. The ecological component of the assessment therefore needs to go beyond water quality and wastewater discharge to include energy and climate. At the Krosno treatment plant, for instance, Masłoń et al (2024) measured energy consumption of 0.25–0.71 kWh/m^3 and energy self-sufficiency of 50.5%. Czekała (2023) reported that in 2021, 100 Polish plants with sludge fermentation produced 367.8 GWh of electricity — against a theoretical potential of about 900 GWh.

What sets this approach apart is the institutional component, designed to capture how public-sector governance affects water and wastewater enterprises, especially in Eastern Europe. The case for including tariff cost coverage is strong: a 2024 survey by the Polish water industry chamber (IGWP, 2024) found that roughly 65% of utilities were running at a loss in Q1 2024, and three out of four had stopped investing.

The model calculates an integral index made up of sub-indices, one for each component. The full set of original indicators was presented in Moroz (2024). This paper focuses only on the 26 new indicators that the author considers necessary in light of the sector's changing conditions: digitalisation of infrastructure, pursuit of energy self-sufficiency, growth of the circular economy and the need to strengthen the ecological and social components.

Table 1: New partial indicators proposed for inclusion in the integral assessment model

N	Component	New partial indicator
1	Resource	Network failure rate (λ) (Tchórzewska-Cieślak and Piegdoń, 2012; Zimoch and Czopik, 2018; Hotłoś, 2007; Piechurski, 2006)
2	Resource	Average network age
3	Resource	CAPEX to revenue ratio
4	Technological	Smart metering penetration (AMI)
5	Technological	SCADA/GIS implementation level
6	Technological	Share of automated processes
7	Technological	Digital twin deployment
8	Technological	AI/ML adoption level
9	Personnel	Share of personnel with digital/IT competencies
10	Personnel	Staff turnover rate
11	Effectiveness	Energy self-sufficiency of wastewater treatment plant
12	Effectiveness	Network rehabilitation rate (IWA PI: Op31)
13	Institutional	Tariff cost coverage ratio
14	Institutional	Access to external innovation financing
15	Social	Continuity of water supply (IWA PI: Op25)
16	Social	Affordability of services

N	Component	New partial indicator
17	Social	Population connected to water supply network (SDG 6.1)
18	Social	Population connected to sewerage network (SDG 6.2)
19	Social	Customer satisfaction index
20	Ecological	Specific energy consumption for water supply (IWA PI: Op39)
21	Ecological	Specific energy consumption for wastewater treatment
22	Ecological	Carbon footprint
23	Ecological	Non-revenue water
24	Ecological	Sewage sludge utilisation rate
25	Ecological	Energy recovery from biogas rate
26	Ecological	Treated wastewater reuse rate

Source: Author's development.

At the third stage, indicators are standardised. Because they use different units and scales, normalisation is needed — for example min-max rescaling or z-scores, as recommended in the OECD Handbook (Nardo et al, 2008). At the fourth stage, weights are assigned. Expert-based weights can be supplemented with data-driven methods such as PCA or Shannon entropy to reduce subjectivity (Nardo et al, 2008).

The additions reflect real changes in the sector. Water and wastewater services use large amounts of energy: in Poland, treatment plants consume 0.3–1.2 kWh/m^3 (Masłoń et al, 2024), compared with an EU average of 1.18 kWh/m^3 (EurEau, 2021) for countries with strict discharge standards. Circular economy indicators mark a shift from 'remove pollutants and dispose' to 'recover resources and reuse'. The 100 Polish plants with fermentation capacity produced 367.8 GWh in 2021, but the potential is roughly 900 GWh (Czekała, 2023).

Replacing health-based social indicators with direct service quality measures — supply continuity (IWA Op25) (Alegre et al, 2016), affordability (OECD 3–5% threshold) (OECD, 2010) and network coverage (SDG 6) — solves a long-standing attribution problem. Disease rates depend on many factors; supply hours and connection rates depend directly on the utility.

For enterprise managers, the integral indicator offers a way to track performance and identify where innovation is most needed. For investors, it can inform valuation and acquisition decisions. For regulators, it allows comparisons at the level of individual firms, sectors, regions or the whole country. The extended model also helps enterprises monitor their progress towards the requirements of the revised EU directive (Directive (EU) 2024/3019), especially on energy self-sufficiency and micropollutant removal.

Summary

This paper has extended the author's seven-component integral indicator of innovative development for water and wastewater enterprises with 26 new partial indicators, responding to three pressures now shaping the sector: rapid digitalisation, the European Union's pursuit of climate neutrality and tighter regulation. The additions span digital transformation (smart metering, SCADA/GIS, automation, digital twins and AI/ML), energy and climate (specific energy consumption, energy self-sufficiency at treatment plants, carbon footprint, biogas energy recovery, sludge utilisation and treated-wastewater reuse) and directly measurable service-quality metrics (supply continuity, affordability and SDG 6 connection rates) that replace health-based proxies whose link to any single utility is hard to establish.

The extended indicator draws on the IWA Performance Indicator System, the European Benchmarking Co-operation and the OECD methodology for composite indicators, while retaining the ecological, social and institutional components that distinguish the water and wastewater sector. In light of its critical-infrastructure status under the NIS2 and CER directives and the energy-neutrality deadline of 2045 set by the revised EU urban wastewater directive (Directive (EU) 2024/3019), the indicator offers enterprise managers, investors and regulators a consistent basis for tracking innovative development and monitoring regulatory compliance.

References

- Act of 26 April 2007 on Crisis Management (Journal of Laws 2022, item 261, 583). [Polish legislation].
- Alegre, H., Baptista, J.M., Cabrera Jr., E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W., Parena, R. (2016) Performance Indicators for Water Supply Services, 3rd ed., London: IWA Publishing.
- Berg, S. (2020) 'Performance assessment using key performance indicators (KPIs) for water utilities: a primer,' Water Economics and Policy, 6 (2), 2050001.
- Cetrulo, T.B., Marques, R.C. and Malheiros, T.F. (2019) 'An analytical review of the efficiency of water and sanitation utilities in developing countries,' Water Research, 161, 372–380.
- Chervan'ov, D. (1999) Menedzhment innovatsijno-investytsijnoho rozvytku pidpryiemstv Ukrainy, Kyiv: Znannia, KOO.
- Chorna, M. and Hlukhova, S. (2012) Otsinka efektyvnosti innovatsijnoi diial'nosti pidpryiemstv, Kharkiv: KhDUKhT.
- Czekała, W. (2023) 'Balance and energy use of biogas in Poland,' Energies, 16 (9), 3910.
- Daniel, I., Ajami, N.K., Castelletti, A., et al (2023) 'A survey of water utilities' digital transformation: drivers, impacts, and enabling technologies,' npj Clean Water, 6, 51.
- Directive (EU) 2022/2555 of the European Parliament and of the Council on measures for a high common level of cybersecurity (NIS2 Directive), Official Journal of the European Union.
- Directive (EU) 2022/2557 of the European Parliament and of the Council on the resilience of critical entities (CER Directive), Official Journal of the European Union.
- Directive (EU) 2024/3019 of the European Parliament and of the Council concerning urban wastewater treatment (recast), Official Journal of the European Union.
- EurEau (2021) Europe's Water in Figures, Brussels: EurEau.
- European Benchmarking Co-operation (EBC) (2024) International Benchmarking Programme, The Hague: EBC Foundation. Available: https://www.waterbenchmark.org.
- Goh, K.H. and See, K.F. (2021) 'Twenty years of water utility benchmarking,' Journal of Cleaner Production, 284, 124711.
- Grigg, N.S. (2025) 'Digital transformation in water utilities: status, challenges, and prospects,' Smart Cities, 8 (3), 99.
- Heiets', V. and Semynozhenko, V. (2006) Innovatsijni perspektyvy Ukrainy, Kharkiv: Konstanta.
- Hotłoś, H. (2007) Ilościowa ocena wpływu wybranych czynników na parametry i koszty eksploatacji sieci wodociągowych, Habilitation thesis, Wrocław: Wrocław University of Technology.
- IGWP — Polish Water Supply and Sewerage Chamber of Commerce (2024) Survey on the financial situation of water utilities, Portal Samorządowy, 28 April 2024.
- Illiashenko, S. (2013) Innovatsii u marketynhu i menedzhmenti, Sumy: TOV Papirus.
- Kariuk, V. (2012) 'Metodychnyj pidkhid do otsiniuvannia innovatsijnoho potentsialu promyslovykh pidpryiemstv,' Aktual'ni problemy ekonomiky, 5 (131), 176–182.
- Kehrein, P., van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J. and Posada, J. (2020) 'A critical review of resource recovery from municipal wastewater treatment plants,' Environmental Science: Water Research & Technology, 6 (4), 877–910.
- Kiparsky, M., Sedlak, D.L., Thompson, B.H. and Truffer, B. (2013) 'The innovation deficit in urban water: the need for an integrated perspective on institutions, organizations, and technology,' Environmental Engineering Science, 30 (8), 395–408.
- Kuzhda, T. (2008) 'Obgruntuvannia metodu sotsial'no-ekonomichnoho otsiniuvannia innovatsijnoho rozvytku,' Ekonomichnyj prostir, 9, 156–161.
- Kwietniewski, M. and Rak, J. (2010) Niezawodność infrastruktury wodociągowej i kanalizacyjnej w Polsce, Warsaw: PAN.
- Lapko, O. (2005) 'Rozvytok systemy upravlinnia naukovo-innovatsijnoiu sferoiu v Ukraini,' Ekonomika i prohnozuvannia, 3, 55–62.
- Maliuta, L. (2011) 'Otsiniuvannia rivnia innovatsijnoho rozvytku promyslovoho pidpryiemstva,' Sotsial'no-ekonomichni problemy i derzhava, 1 (4).
- Marques, R.C. and Simões, P. (2020) 'Revisiting the comparison of public and private water service provision,' Water, 12, 1477.
- Masłoń, A., Czarnota, J., Szczyrba, P., Szaja, A., Szułżyk-Cieplak, J. and Łagód, G. (2024) 'Assessment of energy self-sufficiency of wastewater treatment plants — a case study from Poland,' Energies, 17 (5), 1164.
- Mochernyj, S. (2000) Ekonomichna entsyklopediia, Vol. 3, Kyiv: Akademiia.

- Moroz, E. (2024) ‘Assessing innovation in water supply, sewage, and wastewater treatment enterprises,’ European Research Studies Journal, XXVII (3).
- Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffmann, A. and Giovannini, E. (2008) Handbook on Constructing Composite Indicators: Methodology and User Guide, Paris: OECD Publishing.
- Natividade, J.D.C.B.S., Ferreira, F.A.F., Zopounidis, C., Pereira, L.F., Çipi, A. and Ferreira, J.J.M. (2021) ‘Developing a composite index for intrapreneurial orientation in small and medium-sized enterprises: a comprehensive dual methodology,’ Journal of the Operational Research Society, 72 (7), 1674–1687.
- Nejkova, L. (1990) Analyz effektyvnosty tekhnycheskoho perevooruzhenyia promyshlennykh predpryiatyj, Moscow: Fynansy y statystyka.
- NIK — Supreme Audit Office of Poland (2022) Billions of Litres of Water Wasted in Rural Areas, Audit report, Warsaw: NIK.
- Obaideen, K., Shehata, N., Sayed, E.T., Abdelkareem, M.A., Mahmoud, M.S. and Olabi, A.G. (2022) ‘The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline,’ Energy Nexus, 7, 100112.
- OECD (2010) Pricing Water Resources and Water and Sanitation Services, Paris: OECD Publishing.
- OECD/Eurostat (2018) Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th ed., Paris: OECD Publishing.
- Piechurski, F. (2006) ‘Przyczyny i ocena awaryjności rozdzielczej sieci wodociągowej,’ Wodociągi i Kanalizacja, 1/2006.
- Prokhorova, V. and Mushnykova, S. (2014) ‘Metodyka otsinky rivnia stijkosti innovatsijno-investytsijnoho rozvytku,’ Ekonomika ta upravlinnia pidpryiemstvamy, 2 (26), 44–53.
- Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, Official Journal of the European Union, L 177, 32–55.
- Sakai, H. (2024) ‘Review of research on performance indicators for water utilities,’ AQUA, 73 (2), 167–182.
- Sala-Garrido, R., Mocholí-Arce, M. and Molinos-Senante, M. (2021) ‘Assessing the quality of service of water companies: a ‘benefit of the doubt’ composite indicator,’ Social Indicators Research, 155 (1), 371–387.
- Tchórzewska-Cieślak, B. and Piegdoń, I. (2012) ‘Analiza awaryjności sieci wodociągowej miasta Sanoka,’ Gaz, Woda i Technika Sanitarna, 10, 450–452.
- Vilarinho, H., Pereira, M.A., D’Inverno, G., Nóvoa, H. and Camanho, A.S. (2024) ‘Water Utility Service Quality Index,’ Socio-Economic Planning Sciences, 92.
- Wehn, U. and Montalvo, C. (2018) ‘Exploring the dynamics of water innovation: foundations for water innovation studies,’ Journal of Cleaner Production, 171, S1–S19.
- Yastrems’ka, O. and Blyzniuk, T. (2008) ‘Otsinka innovatsijnoi spryjniatlyvosti pidpryiemstva,’ Ekonomika: problemy teorii ta praktyky, 241 (IV), 748–755.
- Yerina, A. (2001) Statystychne modeliuvannia ta prohnozuvannia, Kyiv: KNEU.
- Zimoch, I. and Czopik, Ł. (2018) ‘Analiza awaryjności sieci wodociągowej jako element zarządzania ryzykiem,’ Instal, 5, 49–53.