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Electricity Consumption and Energy Efficiency Trends in Large Municipal Wastewater Treatment Plants in Slovakia

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Abstract

This study presents a comprehensive evaluation of electricity consumption in 57 large municipal wastewater treatment plants (WWTPs) in Slovakia based on detailed operational data for the year 2024. The analysed facilities represent approximately 3.0 million population equivalents (p.e.), corresponding to about 76% of the total pollution load treated in Slovak municipal WWTPs. Electricity demand was assessed using two key indicators: energy consumption per volume of treated wastewater (kWh/m³) and per population equivalent per year (kWh/p.e.year). These indicators were further analysed in relation to plant size, influent characteristics and the presence of on-site energy generation. The results show that electricity consumption ranged from 0.13 to 1.19 kWh/m³, with an average value of 0.45 kWh/m³. When expressed per population equivalent, values ranged from 18.12 to 133.57 kWh/p.e.year, with an average of 49.33 kWh/p.e.year. A clear relationship was observed between influent organic load (BOD₅ concentration) and electricity consumption, reflecting increased aeration energy demand for higher organic pollution levels. While the kWh/m³ indicator is widely used, the kWh/p.e.year metric proved more suitable for inter-plant comparison, as it better accounts for differences in influent strength. A significant inverse relationship between plant size and specific electricity consumption was identified when using the population-based indicator, confirming that larger WWTPs benefit from economies of scale. This trend was less pronounced when using the volumetric indicator. Despite extensive modernization efforts in the Slovak wastewater sector since 2011, average electricity consumption has remained relatively stable. This suggests that increased treatment requirements and more advanced process configurations have offset potential energy savings. In terms of energy production, 31 of the 57 Slovak WWTPs had on-site electricity generation, mainly through combined heat and power (CHP) units and photovoltaic systems. The

average electricity production reached 8.7 kWh/p.e.year, with a maximum of 24.4 kWh/p.e.year. Plants with energy generation achieved an average self-sufficiency rate of 22.1%. The findings provide a robust national benchmark for electricity consumption in WWTPs and offer valuable insights for future optimization. They also contribute to assessing progress toward energy efficiency and energy neutrality targets outlined in Directive (EU) 2024/3019.

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