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# Energy Efficiency of Small Waste Water Treatment Plants in The Baltic Sea Region – A Comparative Case Study

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**Abstract:**

Presented paper deals with the topic of energy efficiency indexes that were calculated for various locations of small and medium water treatment plants in Europe. Similar size of water treatment plants was chosen for comparison, energy efficiency indexes were calculated using real plant data. Comparative analysis was performed for plants found in the literature. One of the plants uses electrical energy produced by a small photovoltaic plant – its influence on energy efficiency indexes were also taken into account. As proven in the text the energy efficiency indexes of small water treatment plants in the Baltic Sea Region can vary strongly. Location 2 (Sweden) has similar inflow and size to location 1 (Poland) but based on the chemical oxygen demand (COD) it serves only 48% of the people of the polish WWTP, which is a sign of possible high excess water inflows. Efficiency indexes for almost all definitions are best for the Location 3 (Denmark) and also effects of PV energy production allow to lower the energy efficiency indexes by 9%.

**Keywords:** Energy efficiency, Waste water treatment plants, Energy efficiency indexes.

**DOI:**

## 1. INTRODUCTION

Population of Earth is constantly increasing; United Nations estimate the population in the year 2050 to exceed 10 billion [1]. Among them 4 billion people will live in areas with limited or restricted access to water [2]. In order to limit the negative impact of the increasing world population and energy production, energy efficiency indexes are analyzed and ambitious goals are set by the European Union [3]. The overall energy efficiency index should reach an increase of 25% in 2030 with respect to levels from 1990. Waste water treatment plants are important industrial energy consumers and ways of energy efficiency improvement are a visible trend among European municipalities and waste water plant operators. It is obvious that such plants concentrate on water quality and wastewater treatment efficiency but 25% - 40% of operating costs are related to energy consumption [4].

Presented study compares energy efficiency indexes [4] for three exemplary waste water treatment plants WWTP) in the Baltic Sea region. Exemplary WWTPs include Goleniów Water Treatment Plant (Location 1 - Poland), Rőnne - Bornholm (Location 3 - Denmark) and Hőőr (Location 2 – Sweden, combined WWTPs of Lyby and Ormanäs). Their geographical position is presented in Fig. 1. Time evolution of energy efficiency indexes and the influence of renewable energy sources on energy efficiency indexes are also analyzed. Obtained results are compared to indexes published in (for comparable WWTP size) [4].

Comparison of WWTP sizes is given in Table 1. As can be noticed all WWTP are of limited size and are representative for small and medium municipalities. Incoming flow is comparable even though the person equivalent (P.E.) varies strongly. It also has to be underlined that the location 3 is on an island.



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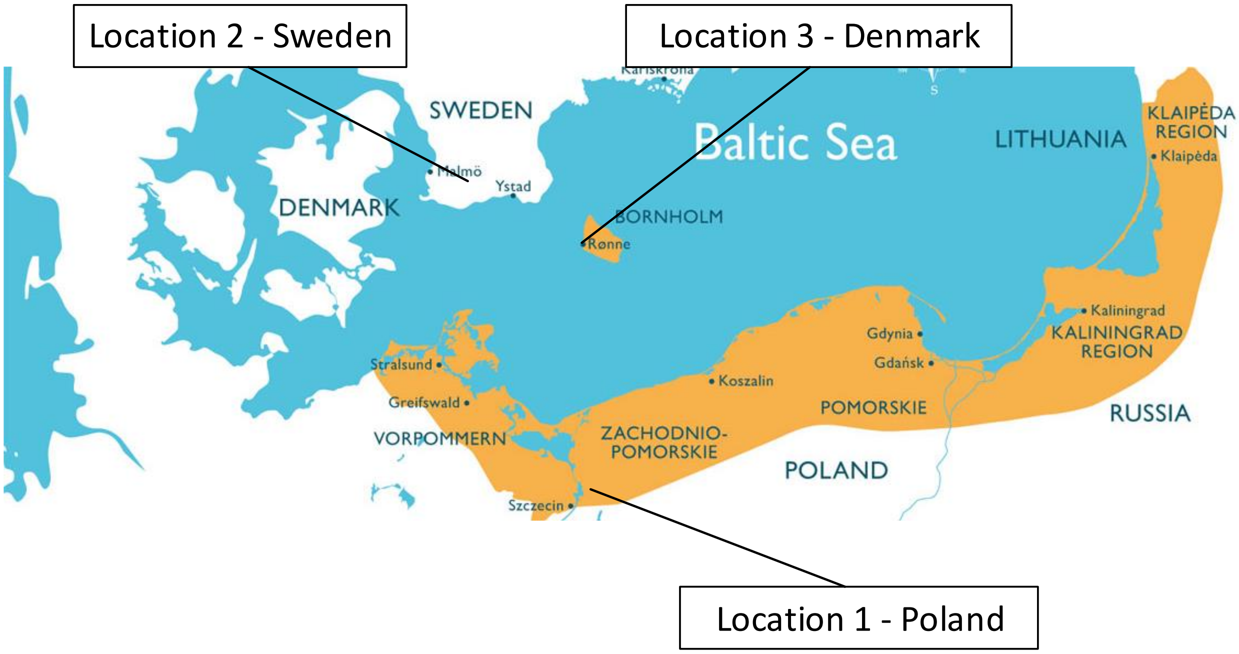


**Figure 1.** Geographical placement of exemplary waste water treatment plants.

Exemplary location 3 (Denmark) produces electrical energy using a photovoltaic installation. Total electrical energy production from this unit was 82 174 kWh in the year 2017. This input is also analyzed regarding total carbon impact of the waste water processing. It is worth to notice that in Location 2 – Sweden the incoming flow is similar to Location 1 – Poland while P.E. in Location 1 is two times higher.

## 2. ENERGY EFFICIENCY INDEXES

Four basic energy efficiency indexes are related to water purification energy consumption calculated as ratios for a person equivalent, standard cubic meter, chemical oxygen demand (COD) and total phosphorous Ntot according to formulas:

$$I_{p.e.} = \frac{P_{el,tot}\,[kWh]}{p.e.[\frac{1}{y}]} \quad (2.1)$$

$$I_{p.e.} = \frac{P_{el,tot}\,[kWh]}{p.e.[\frac{1}{y}]} \quad (2.2)$$

$$I_{p.e.} = \frac{P_{el,tot}\,[kWh]}{p.e.[\frac{1}{y}]} \quad (2.3)$$

$$I_{p.e.} = \frac{P_{el,tot}\,[kWh]}{p.e.[\frac{1}{y}]} \quad (2.4)$$

Where:

- $I_{p.e.}$ – person equivalent (based on COD) energy efficiency index in kWh/person equivalent/year;
- $I_{m3}$ – cubic meter of wastewater treated energy efficiency equivalent in kWh/m3;



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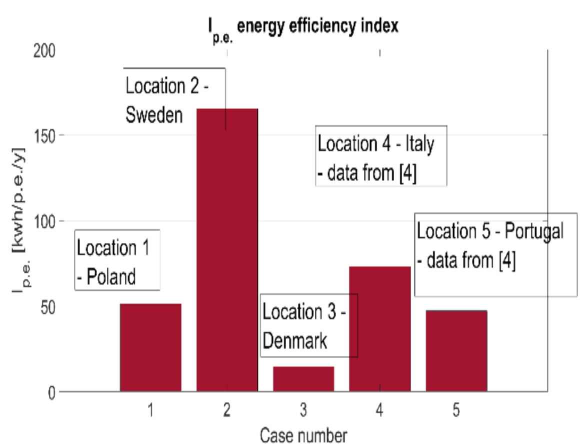
**Table 1.** Exemplary WWTP size comparison based on data from this report and data obtained from [4].

| WWTP | Incoming flow [$m^3$] | Incoming flow exclusive excess water (estimated) [$m^3$] | PE based on COD | PE based on BOD |
|---|---|---|---|---|
| Location 1 – Poland | 2 200 616 | 1 301 975 | 35 828 | 13 666 |
| Location 2 - Sweden | 2 693 939 | 1 346 509 | 17 263 | 16 236 |
| Location 3 - Denmark | 3 190 701 | 1 800 000 | 65 964 | 46 360 |
| Location 4 – Italy, Folgaria, data from [4] | n.a. | n.a. | 24 000 | n.a. |
| Location 5 – Portugal, Alveiro, data from [4] | n.a. | n.a. | 78 000 | n.a. |

- $I_{COD}$ – chemical oxygen demand energy efficiency index in kWh/chemical oxygen demand removal in kg of COD;
- $I_{Ntot}$ – total nitrogen energy efficiency index in kWh/total removed nitrogen in kg;
- $P_{el,tot}$ – annual, total energy consumption in kWh.

The physical meaning of the indexes is:
Equation 2.1 – total energy consumed by the WWTP divided by the number of person equivalent of the plant that is a statistical energy consumption per serviced person;
Equation 2.2 - total energy consumed by the WWTP divided by the total volume of the treated wastewater of the plant that is a statistical energy consumption per a cubic meter of wastewater;
Equation 2.3 - total energy consumed by the WWTP divided by the weight of chemical oxygen demand removed from the wastewater is a statistical energy consumption per a kilogram of removed amount of oxygen that can be consumed by reactions in a measured solution – an index depicting wastewater pollution factor;
Equation 2.4 - total energy consumed by the WWTP divided by the weight of nitrogen removed from the wastewater - a statistical energy consumption per a kilogram of removed nitrogen which also is an index depicting wastewater pollution factor.

Based on data provided by WWTP operators (for Locations 1,2 – from the year 2018, for Location 3 – from 2017) calculations were performed in order to evaluate energy efficiency indexes and compare them with the data provided in [4] for Folgaria (Location 4) and Alveiro (Location 5). Graphical comparison of four basic indexes described above are presented in Fig. 2. For the cases c) and d) data in [4] was either partly or not provided.



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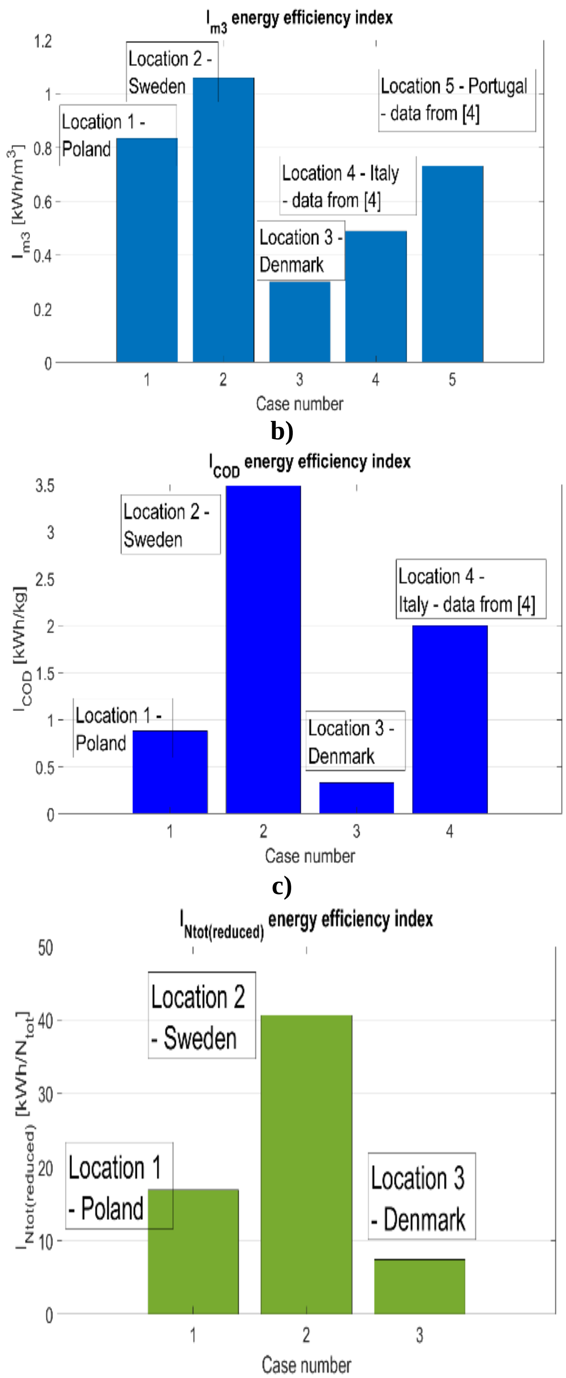
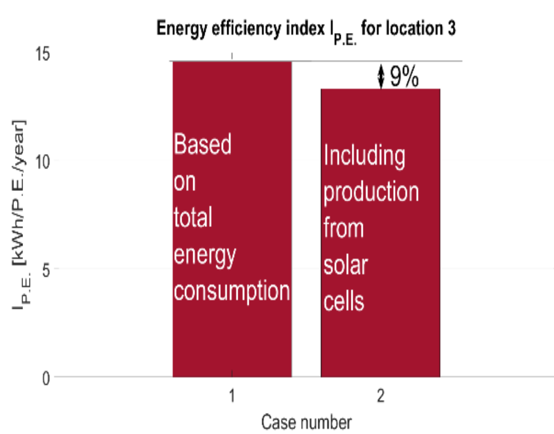



**Figure** 2. Graphical presentation of the basic energy efficiency indexes: **a)** $I_{p.e.}$; **b)** $I_{m3}$; **c)** $I_{COD}$; **d)** $I_{Ntot.}$

As can be noticed best energy efficiency indexes, regardless of its nature, are obtained for the Location 3 – Denmark and worst values were obtained for the Swedish WWTP. The difference is very significant – average energy consumption per person equivalent in Sweden is 11,3 times higher than in Denmark. The probable reason is the non-optimal efficiency of blowers, which can contribute up to 50% of total electrical energy consumption [4]. The efficiency of blowers can vary between 55% and 77% (as an index of blower power to air volume per unit of time – kW/m3/h, [4]). Fine – pore (fine – bubble) aerators offer 3 times higher standard aeration efficiency compared to surface aerators or coarse – bubble systems [5]. This is one of the possible reasons of lower energy efficiency indexes in this location. A second possible explanation of this results is a large volume of excess waters in the sewage system resulting in increased energy consumption for all the stages of wastewater processing. As can be noticed from Table 1 while the PE index of this location is 2,07 times lower than for Location 1 (Poland) the total inflow is comparable and even slightly (122%) higher for Location 2 (Sweden) then in Location 1.

The WWTP in Location 3 has also electricity generation possibilities using a photovoltaic power plant. The installed nominal power of this installation is 93 kWp at nominal array irradiation. The energy produced by the PV plant was subtracted from the total energy consumption of the power plant and the influence of local production on energy efficiency indexes for Location 3 is depicted in Fig. 3. As can be noticed the energy efficiency indexes are improved by 9%.

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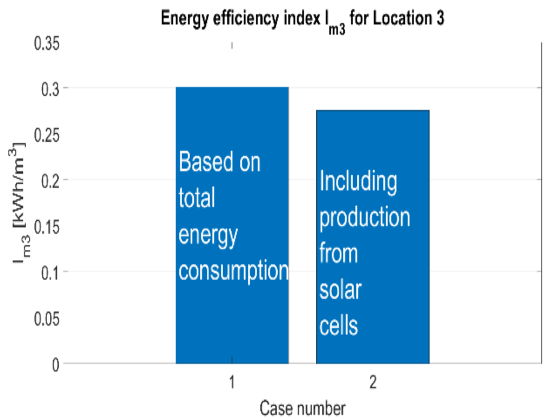


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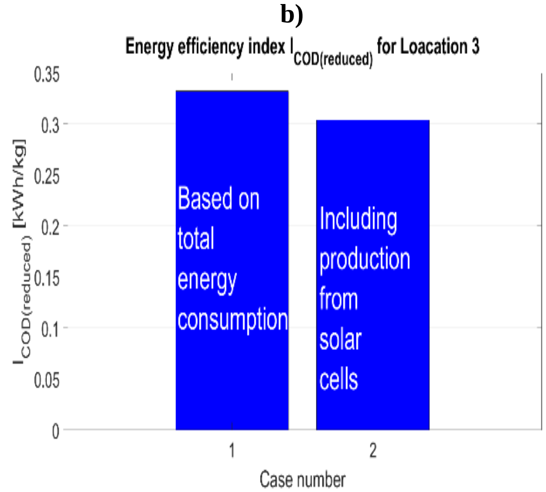


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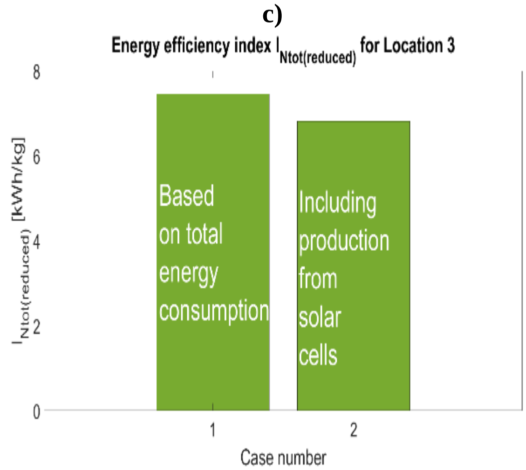


d)

**Figure 3.** The influence of local energy production on energy efficiency indexes for Location 3: **a)** $I_{p.e.}$; **b)** $I_{m3}$; **c)** $I_{COD}$; **d)** $I_{Ntot}$..

As can be noticed local energy production reaching 82 000 kWh annually (with energy sells of 2000 kWh annually) lowers the energy efficiency indexes by 9%. The real energy generation factor of the installation is 0,88 kWh/kWp of installed power per annum. It is typical for locations in northern Europe.

## 3. SLUDGE PRODUCTION COMPARISON

An additional factor that can be compared is the dewatered sludge production with respect to PE, consumed polymer for decanter tanks and consumed electrical energy. Indexes are defined as follows:

$$I_{sludgePE} = \frac{m_{sludge,dewatered}\,[t]}{P.E.} \tag{3.1}$$

$$I_{sludge,polymer} = \frac{m_{polymer}\,[kg]}{m_{sludge,dewatered}[t]} \tag{3.2}$$

$$I_{sludge,Pel} = \frac{P_{el,tot}\,[kWh]}{m_{sludge,dewatered}\,[t]} \tag{3.3}$$

where:
P.E. – person equivalent (based on COD);
$m_{sludge,dewatered}$ – mass of annual dewatered sludge production in tones;
$m_{polymer}$ – mass of polymers consumed for decanter tanks in kilograms;
$P_{el,tot}$ – annual, total energy consumption in kWh.

The physical meaning of the indexes is:
Equation 3.1 – total mass of dewatered sludge divided by the number of person equivalent of the plant that is a statistical mass of sludge produced per serviced person;
Equation 3.2 - total mass of polymers used for sludge processing divided by a total mass of dewatered sludge as an indicator of how much polymers were used for a statistical ton of sludge;
Equation 3.3 - total energy consumed by the WWTP divided by the total weight of the dewaters sludge which is a statistical energy consumption per a ton of sludge depicting energy consumption intensity of sludge generation.



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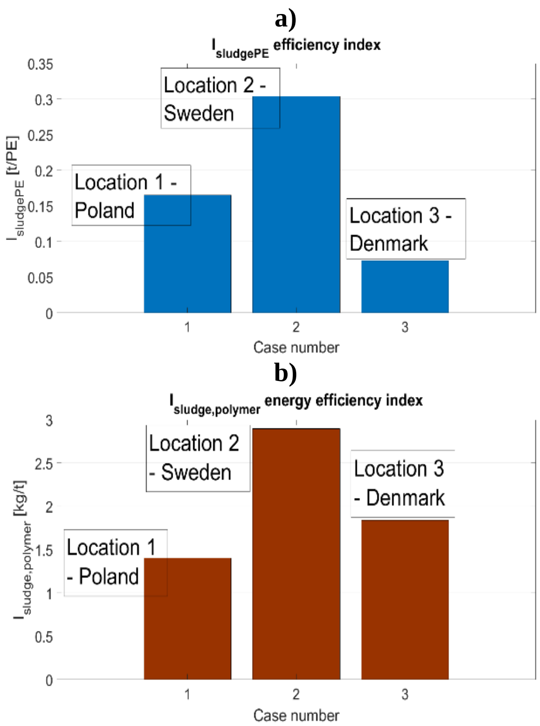


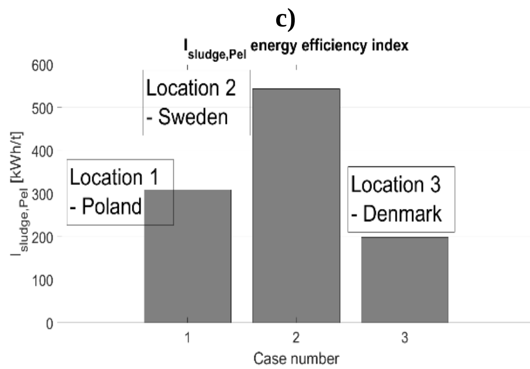


**Figure 4.** Comparison of sludge related indexes for analyzed locations: **a)** $I_{sludgePE}$; **b)** $I_{sludge,polymer}$; **c)** $I_{sludge,Pel}$.

This comparison is provided in a graphical form in Fig. 4. Sludge heavy metal content in sludge can be found in [6]. This data will be compared to results of this study in next part of the research.

**Table 2.** Summary of energy efficiency indexes in selected locations.

| Analyzed location | $I_{p.e}$ [kWh/P.E./annum] | $I_{m3}$ [kWh/m$^3$] | $I_{COD}$ [kWh/kg$_{COD,removed}$] | $I_{Ntot}$ [kWh/kg$_{N,removed}$] | $I_{Sludge,PE}$ [t/P.E./y] | $I_{Sludge,polymer}$ [kg/t] | $I_{Sludge,Pel}$ [kWh/t] |
|---|---|---|---|---|---|---|---|
| Location 1 – Poland | 51,2 | 0,83 | 0,88 | 16,9 | 0,165 | 1,4 | 309,5 |
| Location 2 – Sweden | 165,2 | 1,06 | 3,48 | 40,6 | 0,303 | 2,9 | 543,7 |
| Location 3 – Denmark | 14,6 | 0,30 | 0,33 | 7,45 | 0,073 | 1,8 | 198,7 |
| Location 3 – Denmark (including own solar production) | 13,3 | 0,28 | 0,30 | 6,82 | n.a. | n.a. | 181,7 |
| Location 4 – Italy [4] | 73 | 0,49 | 2 | n.a. | n.a. | n.a. | n.a. |
| Location 5 – Portugal [4] | 47,2 | 0,73 | n.a. | n.a. | n.a. | n.a. | n.a. |



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## 4. CONCLUSIONS

As shown in the paper energy efficiency indexes of small water treatment plants in the Baltic Sea Region can vary strongly. Location 2 (Sweden) has similar inflow and size to location 1 (Poland) but based on the chemical oxygen demand (COD) it serves 48% of the people of the polish WWTP, which is a sign of possible high excess water inflows. Efficiency indexes in almost all definitions are best for the Location 3 (Denmark) and also effects of PV energy production allow to lower the energy efficiency indexes by 9%. It should be underlined again that the size of the solar power plant is limited compared to the total energy consumption (8,5 %). Another interesting indicator is the real electrical energy generation factor of the installation which is 0,88 kWh/kWp of installed power per annum and represents a typical value for locations in northern Europe. A summary of analyzed indexes is presented in Table 2 to allow precise comparison for other researchers. As can be noted the total energy consumption for the person equivalent varies between different WWTP by the factor of more than 12 which was unexpected. This is a very significant difference and needs to be investigated in more details.

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