OPTIMIZATION OF ENERGY CONSUMPTION FOR THE WASTEWATER TREATMENT PLANT USING PHOTOVOLTAIC POWER SYSTEM

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This article presents a solution for optimizing energy consumption for a wastewater treatment plant (WWTP) from Romania using photovoltaic power system (PV). It was considered three situations of realization of the photovoltaic system. The simulations were performed with the PVsyst program. The parameters analyzed were the amount of energy obtained, the percentage of energy recovered, the cost of the system and the amortization period of the investment. The results showed that in the first two scenarios the amortization period is the same, 5 years, although the energy efficiency increased in scenario 2 from 3% to 10%. In the last scenario, the amortization period is too long, 13 years, but the energy efficiency is 44%.

Keywords: photovoltaic power system, PVsyst, energy, WWTP

1. Introduction

Wastewater treatment plants (WWTPs) operators have to face with the problems related to reduce the energy consumption, but achieving process efficiency to comply with pollutants' limitations set in legislation. Also, wastewater treatment generates significant amount of greenhouse gases (GHG) [1]. New legislation in the European Union provide for a mandatory minimum level of 27% for the share of energy from renewable sources in total energy consumption and reduction of GHG emissions with 40% by 2030 and with 80-95% by 2050 [2].

Renewable energy sources has the advantage of their permanence and a reduced environmental impact because they do not emit greenhouse gases [3,4**].**

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These are often used in wastewater treatment plants and are diverse depending on the area located (wind energy, solar energy, hydropower) because wastewater treatment plants are high energy consumers. The most common method is to use photovoltaic power system (PV). These fall into two categories: the classical system and intelligent systems.

Research on the use of renewable energy in wastewater treatment plants is divided into several areas. A study was recently conducted on the use of renewable energy from all existing sources. The results showed that the use of photovoltaic panels can average 21% of the energy required of a treatment plant depending on the geographical area [5]. Photovoltaic power systems are one of the most current and recommended renewable energy technologies due to their high potential for energy productivity. PVs have various environmental benefits, such as low fossil fuel consumption and low CO_2 emissions, also photovoltaic power plants are based on self-consumption (or self-consumption), since input energy is free.

The implementation of photovoltaic power systems in wastewater treatment plants has been studied in several papers taking into account the consumption of aeration energy, the influence of seasonal temperature fluctuations or the balance of micro pollutant flows [6-9]. The results showed that the energy produced is based on the prescribed daily solar irradiation and can vary from 100 W/m^2 and gradually decreases to 10 W/m^2 after 60 minutes, depending on the inclination of the panels [8]. The energy of photovoltaic panels also depends on the geographical positioning of the analyzed area. A study conducted in southern China showed that the average annual radiation is 1306 kWh/m^2 per year. Thus, the optimal angle of inclination of the installation of solar panels is between 14° and 26° [9].

The wastewater treatment plant Polecat Springs from Ireland installed 50 kW solar panels. It consumes about 120,000 kWh of electricity per year, mainly used to pump water an average of 450 m^3/d, from the source to the main tank. Located near Elphin, the PV reduces energy costs by 70% but also reduces carbon dioxide emissions by protecting the environment and allows the local community to benefit from reduced water treatment costs [10]

The implementation of photovoltaic systems began by installing them to produce the energy needed for certain processes in the treatment plant: aeration, coagulation-flocculation, settling [11-13]. Some researchers present the efficiency of a PV for the stage of removal of organic pollutants by electro-oxidation. This technology is simple and light but has a high energy demand, with consequences for both the environment and the economic impact. Thus, experiments for different wastewater (urban and synthetic) at different scales (laboratory and pilot plant) were analyzed. The results showed that the generation of electricity in photovoltaic modules can be described by the linear relationship between current and solar irradiation, because the modules operate in the region where the current does not depend on voltage [14, 15]. In this photovoltaic module generate current intensities of over 10 amp. for 8-9 hours/day [16]. The latest studies present a method of designing photovoltaic systems, taking into account the maximum energy consumption of aeration systems due to air temperature, biological kinetics so that the system produces the maximum amount of energy required [17].

Since 2015, hybrid photovoltaic systems have been developed. Given the production of hydrogen from wastewater, PV systems have been created connected to rechargeable batteries based on hydrogen. The simulations showed that the power supply accurately meets the prescribed daily charging demand and the state of charge of the battery dominates the hybrid strategy of energy management [18]. Such systems were also analyzed in combination with wind turbines in which case an energy efficiency of 90% [19] was obtained. The implementation of a combined system between a photovoltaic system integrated in buildings (BIPV) and a heat pump system (WWS) with wastewater (WWSHP) led to an energy efficiency of 72.23% while their operation in individual system would be taken to 20.93% and 11.82% respectively [20, 21]. A hybrid system consisting of photovoltaic panels and the production of energy from biogas obtained in anaerobic digestion was tested for several configurations depending on the degree of inclination of the panels and the amount of biogas obtained. The PV-bio hybridization power unit was studied both for power supply and finished for the power station in two configurations PV-bio-hybrid power unit in Phoenix and PV-bio-hybrid power unit in Lansing. The results showed that in the first case it resulted in a PV area of 4032 m^2 and a quantity of biogas of 35 m^3 and in the reservoir 2,521 m^2 respectively 105 m^3 [22].

In 2019, the first study appeared that evaluates the way in which photovoltaic panels produce energy according to the demand of the wastewater treatment plant. The photovoltaic system was installed mainly in hybrid configurations with anaerobic digestion. In these plants, biogas contributed 25-65% to the total energy demand, while solar energy provided 8-30% of the necessary [23]. In northwestern Algeria, such a PV system was implemented based on the energy balance, the surface of the PV installation and the cost of the energy level, which led to the coverage of 53% of the electricity load of the treatment plant. Regional energy consumption can be reduced by 2% during the day [24]. An important problem in the implementation of PV systems is their lowering. Floating photovoltaic is a new design solution for photovoltaic (PV) plants. Floating photovoltaic systems (FPVS) are normally installed on water bodies, such as natural lakes or dam reservoirs, and offshore solutions are also being researched. Such technology has attracted worldwide attention and has already been deployed in several countries, such as Japan, South Korea, India and the USA. These systems not only had very high energy efficiency but also led to a reduction in water evaporation [25].

In this article, it is analyzed a PV for a wastewater treatment plant for Romania. Depending on the energy needs of the WWTP, the surplus will be injected into the national network. In Romanian, for energy consumed from renewable sources, in the case of industrial consumers, it saves 0.4-0.5 RON/kWh (with all taxes included) and for its injection into the network the selling price is 0.23 RON/kWh [26]. It was also analyzed the situation in which WWTP could become prosumer in which case the proposed photovoltaic system must not produce the maximum of 100 kW.

2. Material and methods

In the framework of the current research the simulations were performed with the PVsyst program. PVsyst is a software that can propose and simulate a photovoltaic system and it offers the following advantages: it is based on a quick and simple procedure; it has the ability to import weather data as well as personal data from multiple sources; it can be set the required power and the characteristics of the area of interest; it contains a big database of photovoltaic panel models and the inverter [27]. The modelling and simulation was performed in the Photovoltaic Panels laboratory at the National Research-Development Institute for Electrical Engineering ICPE-CA.

The wastewater treatment plant analyzed uses advanced biological treatment SBR (nitrification, denitrification and phosphorus removal), aerobic sludge stabilization, dewatering, storage, chemical disinfection. Advanced biological treatment SBR is one of the biggest consumers of energy among biological treatment processes [28]. Due to the fact that the WWTP is located in the coastal area, the wastewater flow is much higher in summer than in other seasons. In terms of energy consumption and consumption varies depending on the season. The annual energy consumption varies from 1500 MWh/year to 2000 MWh/year. The results are presented in Fig. 1.

The daily load curve was taken into account in the simulation. It depends on: wastewater flow, weather data and whether it is summer or not. Thus, 4 daily load curves were identified for each season. The measurements were taken for 2019 for the middle day of a season.

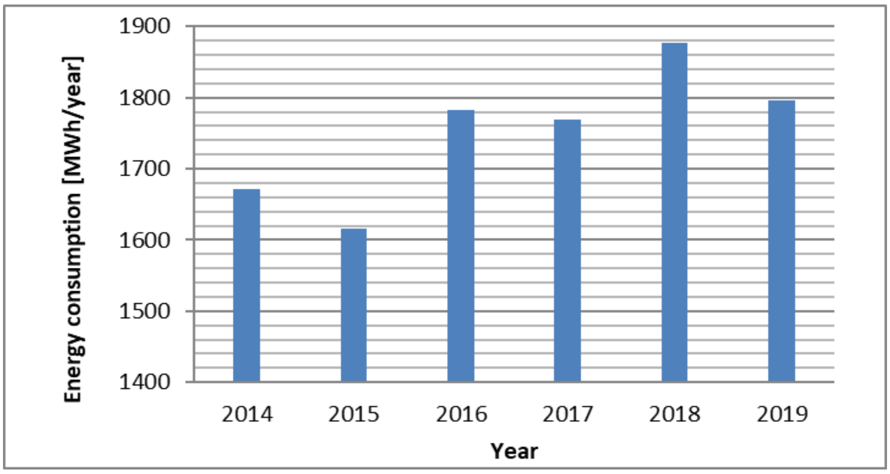

Fig. 1. Annual energy consumption of WWTP

Figs. 2-5 shows the daily variation of energy consumption for the 4 seasons. It can be seen that during the summer there is the highest energy consumption. It decreases slightly in autumn but in winter and spring energy consumption decreases by half.

The first step, in PVsyst program, the geographical area of interest was selected. These means that and the meteorological data were automatically imported. It were selected the geographical orientation of the location of the WWTP, the angle of inclination of the land on which they will be mounted, the type of photovoltaic panels, inverters and the number of modules.

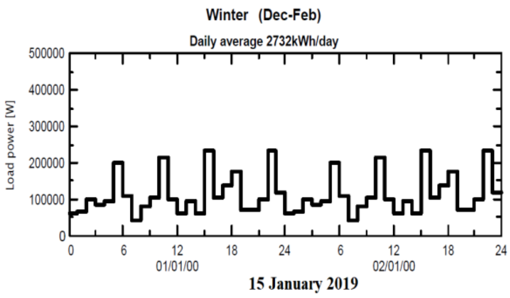

Fig. 2. Daily load curve for the winter period

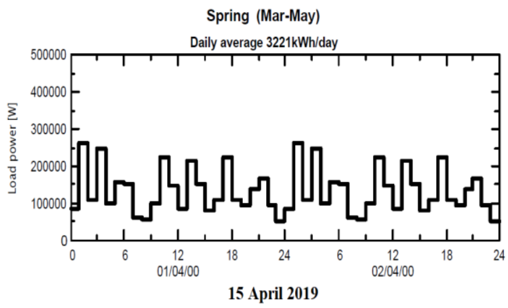

Fig. 3. Daily load curve for the spring period

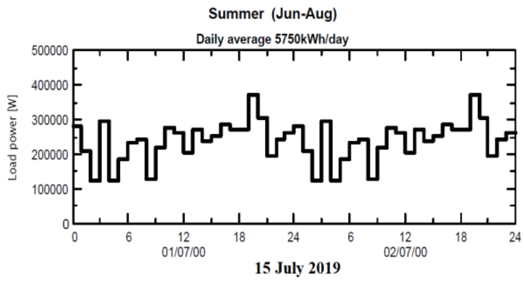

Fig. 4. Daily load curve for the summer period

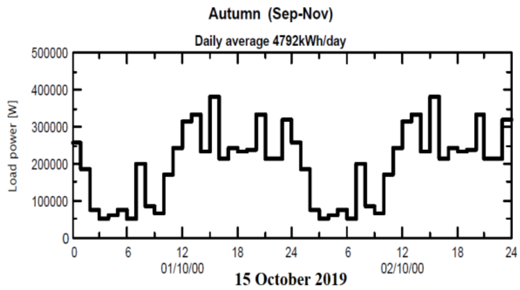

Fig. 5. Daily load curve for autumn period

In the study case, three scenarios were analyzed. The first scenario (C1) was considered, as the mounting surface of the photovoltaic panels, the surface of the roofs of the buildings available in the WWTP. In the second one (C2), was considered the possibility of the wastewater treatment plant becoming prosumer. In this case, the maximum amount of energy produced by the PV must be 100kW. The last scenario (C3), was analyzed the situation in which PV would produce all the energy necessary for the wastewater treatment plant. In this situation, the installation must be done on an adjacent area. A lake has been identified near the WWTP where the system can be installed.

3. Results and Discussion

Scenario1: Following an analysis regarding the existing buildings in the WWTP, two orientations were intensified: O1: S-E and O2: N-V. In the first scenario, was taken into account that the photovoltaic panels are installation only on their roofs. In the PVsyst program were set the geographical positioning of the WWTP, the building orientations, photovoltaic panel type Altius Fotovoltaic model AFP-60-320W, inverter type Huawei Technologies model SUN2000-15k TL and load curve of the treatment plant. The result was a system of 60 modules on O1 and 60 modules on O2 and 2 inverters. The chosen system produces a quantity of 33 kW.

The simulation results showed that the analyzed wastewater treatment plant records an energy consumption of 1507.3 MWh/year and the proposed photovoltaic system produces 47752 MWh/year. In case of implementing this solution, the WWTP would need another 1460.3 MWh/year from the national network. If this solution will be implemented the costs of electricity would decrease by 4865 euro compared to the initial costs. Considering the cost of the system of 25000 euro it can be amortized in 5.1 years. This period is favorable but the energy obtained represents only 3% out of total energy needed.

Scenario 2: In the second scenario, was taken into account the situation in which the PV produces 100kW so the watwater treatment plant can be prosumer.

It were maintained the two orientations from scenario 1 and the type of photovoltaic panel and inverter. It was obtained 198 modules for each orientation. The results show that the system produces 150.41 MWh/year and in order to cover the needs, another 1359.7 MWh/year is consumed from the national network. And in this case there was no energy that could be injected into the the national network. In conclusion, the wastwater treatment plant cannot become a prosumer.

If this scenario were taken into account, the electricity costs would decrease by 15570 euro. Considering the cost of the system of 85000 euros it can be amortized in 5.13 years. In this case the amortization period is favorable and the energy obtained represents 10% out of total energy needed.

Scenario 3: Following the analysis of previous scenarios, it was observed that the WWTP has very high energy consumption and the installation of PV only on the roofs of buildings covers only 3% of the energy needs. Also, this cannot be a prosumer because all the energy produced by the system is consumed and covers 10% of the total required. Consequently, it was considered an PV that would produce all the energy needed. In this scenario, an adjacent area is required for the installation of photovoltaic panels. Analyzing the location of the treatment plant, two locations were identified: on the edge of the aeration tanks and on the lake near the WWTP.

For this solution, 2700 modules were obtained for each orientation, which produce a total of 2099.4 MWh/year. In this case, the treatment plant will consume 670.23 MWh/year from the photovoltaic panels (44% of the total energy demand) and 837.1 MWh/year from the national network. The rest of the energy obtained of 1382.7 MWh/year cannot be injected into the national network because the system exceeds the maximum limit allowed for energy-producing prosumers.

Following the economic calculation for this scenario, the electricity costs would decrease by 62860 euro. Considering the cost of the system of 800000 euro it can be amortized in 12.72 years. In this situation, the payback period is much too long. Fig. 6 presents the results of the 3 analyzed situations. It was observed, in the first 2 scenario, that the amortization period of the investments is the same although the energy efficiency increased in scenario 2, compared to 1 from 3% to 10%. In the last situation the amortization period is very long although the energy obtained covers almost half of the energy needs.

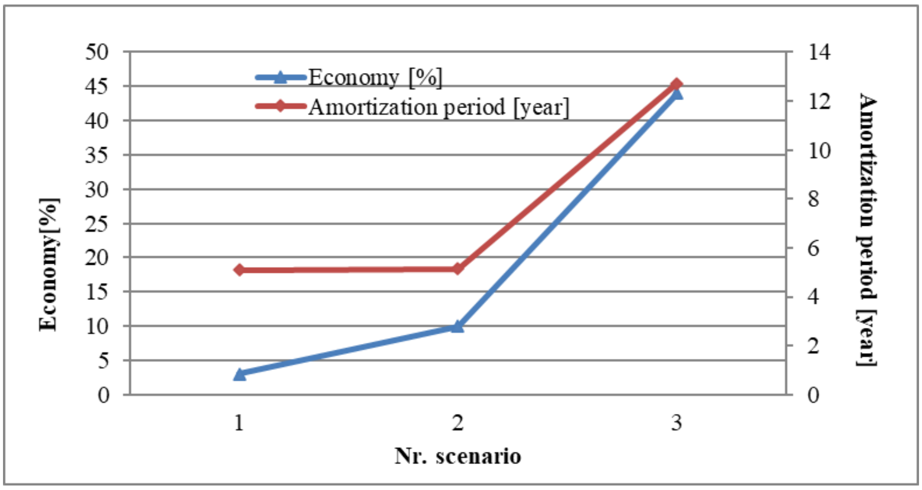

Fig. 6. Comparative results for the 3 analyzed scenarios

4. Conclusions

In this paper, simulations were performed using the PVsyst program for a photovoltaic power stations for a wastewater treatment plant in Romania. It were considered three scenarious: C1- it were considered, as the mounting surface of the photovoltaic panels, the surface of the roofs of the buildings available in the WWTP; C2 - it was considered the possibility of the weastewater treatment plant becoming prosumer; C3 -it was analyzed the situation in which PV would produce all the energy necessary for the wastwater treatment plant.

The results of simulations showed that the wastwater treatment plant has too high an energy consumption that it cannot be prosumer. The amortization period of the investment remained constant for the first 2 situations. The development and implementation of a PV system related to all the necessary amount of energy leads to obtaining a surplus of energy that is difficult to manage and the amortization period of the investment is too long. Taking into account all these conclusions, researches are in continuous development. The following solutions will be analyzed: mounting of 300 photovoltaic panels on the roof of the buildings considering three orientations and mounting the photovoltaic panels on the ground, taking into account a single orientation. The development of an energy storage system for scenario 3 will also be analyzed.

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R E F E R E N C E S

[1] *L.D. Robescu, C. Boncescu, D.A. Bondrea, E. Pre*sura - Chirilescu, Impact of wastewater treatment plant technology on power consumption and carbon footprint, International Conference on ENERGY and ENVIRONMENT (CIEM), **Proceedings Paper,** 2019, pp. 524-528

[2] Ministry of Environment, Package Energy - Climate Change, 2014, http://www.mmediu.ro/categorie/pachet-energie-schimbari-climatice/88

[3]. *I.I. Panaitescu*, Managementul operational al statiilor de epurare, teza de doctorat, Bucuresti, 2014.

[4]. *D. Nugent*, *B.K. Sovacool,* Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey, Energy Policy, **Vol. 65**, 2014, pp. 229-244

[5]. *S.H. Hassan Ali, M. Lenzena, F. Sackb, M. Yousefzadeha*, Electricity generation and demand flexibility in wastewater treatment plants: Benefits for 100% renewable electricity grids, Applied Energy, **Vol. 268**, 2020, 114960

[6]. *K. Lertpocasombut, S. Sirimontree, B. Witchayangkoon, C. Thongchom, V. Winoto, S. Keawsawasvong,* The renewable energy sources for municipal wastewater processes in thailand: a case study of the nonthaburi wastewater treatment plant, Civil and Environmental Engineering, **Vol. 0 (0)**, Published Online: 15 Nov 2021

[7]. *H Alm El Din Mohamad, M. Hemdan, A. Alm El Din Bastawissi, Alm E lDin Mohamad Bastawissi, H. Panchal, K.K. Sadasivuni,* Industrial wastewater treatment by electrocoagulation powered by a solar photovoltaic system, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, **Vol 43(24),** Published Online 13 July 2021

[8]. *S. Zhang , X. Pang, Z. Yue, Y. Zhou, H. Duan, W. Shen, J. Li, Y. Liu, Q. Cheng,* Sulfonamides removed from simulated livestock and poultry breeding wastewater using an in-situ electro-Fenton process powered by photovoltaic energy, Chemical Engineering Journal, **Vol. 397**, 2020, 125466

[9]. *X. Yang, J. Wei, G. Ye, Y. Zhao, Z. Li, G. Qiua, F. Lia, C. Weia,* The correlations among wastewater internal energy, energy consumption and energy recovery/production potentials in wastewater treatment plant: An assessment of the energy balance , Science of The Total Environment, **Vol. 714,** 2020, 136655

[10]. Wastewater treatment plant Polecat Springs Solar PV, Irlanda,3 martie 2020

[11]. *C.J. Nawarkar, V.D. Salkar,* Solar powered Electrocoagulation system for municipal wastewater treatment, Fuel, **Vol. 237**, 2019, pp. 222-226

[12]. *M.P.M. CombattDr., W.C.S. AmorimM.Sc., E.M.S. BritoM.Sc., A.F.CupertinoDr., C.S. MendonçaDr., H.A.PereiraDr.,* Design of parallel plate electrocoagulation reactors supplied by photovoltaic system applied to water treatment, , Computers and Electronics in Agriculture, **Vol. 177,** 2020, 105676

[13]. *X. Yang, J. Wei, G. Ye, Y. Zhao, Z. Li, G. Qiua, F. Lia, C. Wei*, The correlations among wastewater internal energy, energy consumption and energy recovery/production potentials in wastewater treatment plant: An assessment of the energy balance, Science of The Total Environment, **Vol. 714**, 2020, 136655

[14]. *E.nAlvarez-Guerra, A. Dominguez-Ramos, A. Irabien*, Photovoltaic solar electro-oxidation (PSEO) process for wastewater treatment, Chemical Engineering Journal, **Vol. 170 (1)**, 2011, pp. 7-13

[15]. *C.M. Fernández-Marchante, F.L. Souza, M. Millán, J. Lobato, M.A. Rodrigo,* Improving sustainability of electrolytic wastewater treatment processes by green powering, Science of The Total Environment , **Vol. 754**, 2021, 142230

[16]. *S.O. Ganiyu, L.R.D. Brito, E.C.T. de Araújo Costa, E.V.dos Santos, C.A. Martínez-Huitle*, Solar photovoltaic-battery system as a green energy for driven electrochemical wastewater treatment technologies: Application to elimination of Brilliant Blue FCF dye solution, Journal of Environmental Chemical Engineering, **Vol. 7(1),** 2019, 102924
[17]. *A. Colacicco, E. Zacchei*, Optimization of energy consumptions of oxidation tanks in urban wastewater treatment plants with solar photovoltaic systems, Journal of Environmental Management, Vol. 276, 2020, 111353
[18]. *W. Wu, V.I. Christiana, S.A. Chen, J.J. Hwang*, Design and techno-economic optimization of a stand-alone PV (photovoltaic)/FC (fuel cell)/battery hybrid power system connected to a wastewater-to-hydrogen processor, Energy , **Vol. 84**, 2015, pp. 462-472
[19]. *H.T. Nguyena, U. Safder, X.Q. Nhu Nguyen, C. Kyoo Yoo*, Multi-objective decision-making and optimal sizing of a hybrid renewable energy system to meet the dynamic energy demands of a wastewater treatment plant, Energy, **Vol. 191**, 2020, 116570
[20]. *K.J. Chae, J. Kang*, Estimating the energy independence of a municipal wastewater treatment plant incorporating green energy resources, Energy Conversion and Management, **Vol. 75**, 2013, pp 664-672
[21]. *M. Araz, A. Hepbasli, E. Biyik, M. Shahrestani, R. Yao, E. Essah, L. Shao, A.C. Oliveira, O. Ekren, H. Günerhan*, Performance evaluation of a building integrated photovoltaic (BIPV) system combined with a wastewater source heat pump (WWSHP) system, Energy Procedia, **Vol. 140**, 2017, pp 434-446
[22]. *M. Bustamante, W. Liao*, A self-sustaining high-strength wastewater treatment system using solar-bio-hybrid power generation, Bioresource Technology, **Vol. 234**, 2017, pp. 415-423
[23]. *A. Strazzabosco, S.J. Kenway, P.A. Lant*, Solar PV adoption in wastewater treatment plants: A review of practice in California, Journal of Environmental Management, **Vol 248**, 2019, 109337
[24]. *M. Beya, A. Hamidat, T. Nacerd*, Eco-energetic feasibility study of using grid-connected photovoltaic system in wastewater treatment plant, Energy, Available online 3 November 2020, 119217, In Press,
[25]. *M. Rosa-Clot, G. M. Tina, S. Nizetic*, Floating photovoltaic plants and wastewater basins: an Australian project, Energy Procedia, **Vol. 134**, pp. 664-674
[26]. https://www.anre.ro/ro/legislatie/prosumatori - Prețurile aplicabile la comercializarea energiei electrice produse de către prosumatori deținători de centrale electrice cu putere instalată de cel mult 100 kW (Prices applicable to the marketing of electricity produced by prosumers owning power plants with an installed capacity not exceeding 100 kW), 2018
[27]. https://www.pvsyst.com/
[28]. *Y. Gu, Y. Li, X. Li, P. Luo, H. Wang, Z. P. Robinson, X. Wang, J. Wu, F. Li*, The feasibility and challenges of energy self-sufficient wastewater treatment plants, Applied Energy, **Vol. 204**, 15 October 2017, Pages 1463-1475