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A Study on Improving Economy Efficiency of Pumping Stations Based on Tariff Changes

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Abstract: In this paper, research on improving the economic efficiency of 38 drainage pumping stations was undertaken. Particular attention was paid to the effectiveness of activities without considering any expenditures. Energy costs for this type of machine are usually high, approximately 45% of the total maintenance cost. The main assumption of this work was the selection of appropriate energy tariffs to reduce operating costs. Liquid transport in any economy consumes significant amounts of electricity, estimated at 20–30% of the total electricity production. The optimization of the energy consumption of pumping processes is, therefore, very important. While analyzing the choice of energy tariffs, we designed profitability ratios (PR) specifically for different daily time zones. With the forecasted distribution of energy demands for different daily time zones (usually 2 or 3 zones), it was possible to compare multi-zone tariffs with 24 h tariffs. The profitability of the tariffs was decided by the value of the PR indicator. The lower, the better. In practice, this meant that the analyzed multi-zone tariffs, in most cases, are more profitable compared to single-zone tariffs. In the Polish energy system, each entrepreneur, depending on the connection power, has a right to choose a particular energy tariff from three tariff groups, i.e., high (A), medium (B), and low (C) voltage. In the case of land reclamation pumping stations, energy tariffs are usually from groups B and C. The choice of tariffs largely depends on the contracted capacity and is determined by tariff regulation. Nowadays, the current energy system forces entrepreneurs to declare a connected power load at the level corresponding to the maximum use of the production potential. Lack of knowledge of the hydrological regime, quite common for land reclamation pumping stations, usually results in overestimating the contracted capacity. When comparing the effect of changing tariffs, it was found that the profitability of this method is significant. The four-year study period (2010–2013) showed that active energy in the multi-part tariffs of groups B and C is on average 10.2% cheaper than in the single-part tariffs and varies in a wide range from 2% to 20.4%. The analysis carried out on 38 drainage pumping stations shows that for only five pumping stations could changing the current tariff be unjustified. In the other cases, the four years of analysis demonstrates that changing the current energy tariff could reduce electricity costs by approximately 5%., i.e., approximately PLN 124,000 per year (approximately EUR 27,000).

Keywords: pumping stations; energy tariff; economic efficiency

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1. Introduction

Energy is a fundamental requirement for domestic and industrial sectors. The alarming rate of increase in the world's population and the economy has led to enormous energy consumption [1]. The world's energy usage is expected to increase by 30% from 2016 to 2030 [2]. Moreover, according to the US Energy Information Administration [3], by 2050, global energy use will increase nearly 50% compared with 2020—primarily a result of non-Organisation for Economic Co-operation and Development (OECD) member countries' economic and population growth, particularly in Asia. According to the Local Data Bank of Statistics Poland (GUS) [4], in Poland in 2020, electricity consumption amounted to 161.0 TWh, of which 42.5% was in industry and construction. As Jędral [5] reports, the demand for energy in Poland, especially electricity, is growing by approximately 1.5% per year. As per the International Energy Agency (IEA), electric motors consume almost half of the world's energy production and are responsible for nearly 70% of total electricity consumption in industries [6]. According to the report made by the European Commission (EC) [7], pumping systems account for nearly 22% of the energy supplied by electric motors in the world, as shown in Figure 1.

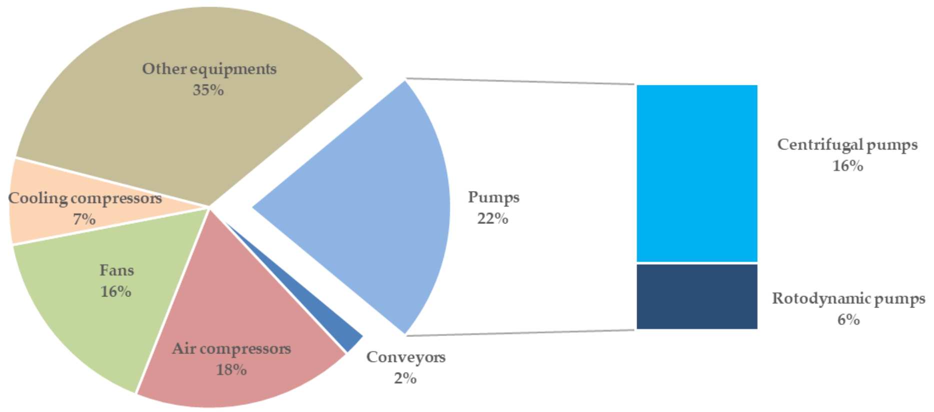

Figure 1. Energy consumption for different applications of electric motors.

These data are confirmed by studies by the United States Department of Energy/Lawrence Berkeley National Laboratory and the European Commission, which show that more than 20% of global motor electrical energy consumption is by pumps [8]. This research also indicates that the initial cost of the pump is only a fraction of the total life cycle cost (LCC) [9] and concludes that the operating cost of a pump dominates its LCC. The operation and maintenance cost was almost 92 to 97 percent of the total cost. According to the research, optimization reduces pump operation costs by approximately 10–20%. However, comparing economic benefits per country would be too complex because the effects of optimization differ depending on each country's power cost estimation system and the existing operations [10]. As reported by [11], the greatest expense of LCC is electricity. In municipal environments, LCC can be as high as 85%. In the case of drainage pumping stations, electricity costs account for 22.5 to 70.9% of operating costs [12]. It is clear that the biggest saving opportunity over the life cycle of a pumping system lies within the electrical energy costs. When physical elements can not be changed (electric engine, pump, variable speed drive (VSD), etc.), the energy cost is related to electricity consumption and the electricity price structure. To minimize the electricity cost of the pump station, electricity consumption needs to shift from peak time to off-peak time or standard time as much as possible. This is called load shifting (LS) [13]. However, in the case of different types of drainage pumping stations [14], atypical pumping systems, and various operating conditions, LS could be troublesome.

This study aimed to determine the improvement of economic efficiency by applying the mechanism of optimizing energy tariffs using data mainly from energy bills. In this study, 41 drainage pumping stations were analyzed. However, due to gaps in the data on pump operation time and information on electricity consumption, only 38 stations were taken into account. This study uses profitability ratios that determine the percentage increase (decrease) in the economics of using a given tariff in relation to the pump operation time between 2010–2013. Forecasting models adjusting the pump operation time to the given tariff and off-peak zones were not analyzed. This study is of a cognitive nature, which could give rise to further research.

2. Market Energy in Poland—Structure of Tariffs Energy

The Polish energy market for electricity and natural gas is one of the largest markets in the European Union and the only one in recent years characterized by a steady increase in the consumption of these commodities [15]. The continuity and stability of electricity supplies in Poland are guaranteed by a group of entities creating subsystems within the National Power System (NPS). These entities are separate companies subject to independent institutions and regulations. The subsystems that make up the NPS are the generation subsystem, transmission network, and distribution network. Their functioning is regulated by numerous legal Acts created by the European Union and Poland's government. Among the National Acts in Poland, the most important is the Energy Law from 10 April 1997 [16], which takes into account the directives of the European Communities. There is also a set of documents named "Energy policy until . . . " that groups the goals and directions of the national energy economy for the next couple of years. Until 2020, the operative Act in this series was the "Energy Policy of Poland until 2030" [17]. From 2 February 2020, the Council of Ministers approved a new Act: "Energy Policy of Poland until 2040" [18]. According to this document, Poland's policy changes in the broadly understood energy sector have been based on three pillars: fair transition, a zero-emission energy system, and a significant improvement in air quality. Additionally, the European Commission, as a part of the European Green Deal, proposed to reduce green gas emission by 2030 to at least 55% compared to 1990 [19]. This package set three targets:

- cut greenhouse gas emissions by at least 40% (compared to 1990);
- increase the share of renewable energy by at least 32%;
- improve energy efficiency by at least 32.5%.

The demand side of the retail electricity market in Poland consists of a couple of end-user groups. In total, there are approximately 17.05 million end-users, and among them, 90.3% (15.4 million) are customers belonging to tariff group G, which includes the majority of household consumers (over 14.5 million). The rest of the end-users are customers who belong to tariff groups A, B, or C. The first two groups, A (top strategic clients) and B (big key clients), include customers connected to high and medium voltage grids, whereas group C contains customers supplied from the low voltage grid. All three groups consume electricity to maintain their business activity, and they are referred to as commercial customers [15].

A significant issue in the Polish electricity market, since the change in the late 1990s, is the collection of detailed information on the electricity consumption of the individual consumers of tariff groups A, B, and C, supplied from different voltage levels. Knowledge of load schedules based on hourly measurements has become the basis for electricity sales forecasting and customers clustering [20]. Regarding financial systems, the electricity billing system in Poland is well developed. The third-party access (TPA) rule (now regulated by [21]) has been functioning in the Polish energy market since 2007. Users can buy energy from any seller. The billing system is normalized, and users are classified according to the voltage from which they are powered and the protection used. End users (companies and households) have the right to choose an electricity producer, but the choice of the distributing company (final supplier) depends on geographic location. The time zones differ between sellers and the season. Energy companies set tariffs for gaseous fuels or energy under the rules set out in the provisions of the Act [16] and administrative regulations issued based on this law. In the field of electricity, these provisions are the ordinance of the Minister of Energy, henceforth called "the Tariff Regulator" [22]. Tariffs are shaped in such a way as to equalize the load curve. During periods of significant energy consumption (usually from 6 a.m. to 1 p.m. and from 3 p.m. to 10 p.m. on weekdays), energy is more expensive, while in periods of reduced demand (from 10 p.m. to 6 a.m., and from 1 p.m. to 3 p.m., and weekends), the price is lower. These periods are called peak hours and off-peak hours. Each of the system operators (setting prices for distribution fees), and each of the sellers, can set their hours (of course, they must be later approved by the President of the URE under Energy Law) [16]. Each of the tariffs is created according to the scheme, by Article 6, Act 1 of the Tariff Regulations (Table 1). For example, tariff B21 means that the consumer uses the medium voltage grid, has energy receivers with a total power exceeding 40 kW, and is billed in one zone (one price rate for 24 h a day).

Table 1. Composition of tariff groups according to Tariff Regulation Article 6, Act 1.

Tariff Symbol X_1,X_2,X_3,X_4		
X_1	B	Consumer of energy from the medium voltage grid
	C	Consumer of energy from the low voltage grid
X_2	1	Contracted capacity ≤ 40 kW
	2	Contracted capacity > 40 kW
X_3	1	One time zone (24 h)
	2	Two time zones (off-peak, on-peak)
	3	Three time zones (off-peak, mid-peak, on-peak)
X_4	a	Division of the day into peak and off-peak
	b	Division of the day into a day and night

For commercial purposes, simultaneous tariffs may have different names from different vendors and operators of the distribution system. As a result, it is difficult to compare the offers of individual sellers and choose the optimal tariff. Theoretically, a diversified tariff offers consumers the possibility of tailoring the offer to their needs. In practice, with relatively low electricity prices, a multitude of tariffs leads to a situation in which consumers often do not try to assess their consumption [23,24]. As a result, this system does not encourage pro-saving behaviours. These observations confirm research in the context of market liberalization in Europe in general [25] and tariff systems in Poland specifically [26,27].

Energy tariff structures are common demand-side management (DSM) and demand response (DR) mechanisms used to improve the energy system in terms of consumption [28,29]. Through the application of different energy pricing structures (e.g., time-of-use rates) and charges (e.g., energy usage and peak power demand charges) in different billing terms, consumers are encouraged to change their habits. These mechanisms incentivize the reduction or shift of peak power demands at specific times for a specific duration, avoiding investments in additional infrastructure by balancing energy use and, consequently, reducing greenhouse gas (GHG) emissions [30].

3. Materials and Methods

3.1. Study Site Characterization and Analyzed Data

This study was carried out based on an analysis of 41 drainage pumping stations out of 50 in the Greater Poland Voivodeship of Poland (Figure 2). Until the end of 2017, these facilities were administered by the Department of Drainage and Water Administration in Poznan (WZMiUW). Since 1 January, the main entity responsible for national water management has been the National Water Management Authority (RZGW) [31]. According to [32], RZGW administrates 587 drainage pumping stations. These facilities have an impact of over 608,000 ha. According to the author's conservative estimates, the total power of all pumps is about 78 MW. In the analyzed area, these pumping stations with a total capacity of over 4.7 MW are responsible for water management in an area of over 64,000 ha (Table 2). Detailed research carried out on one of the facilities showed the possibilities of improving energy and economic efficiency [33]. Therefore, the study undertook the analysis of a larger number of facilities, limited to economic improvements. For this purpose, pump operation times, partly from operating logs and the monitoring system, and general operating costs of the pumping station were analyzed. The pumping costs were extracted from operating costs by analyzing 1870 electricity bills from 2010–2013 in detail. From this information, the amount of kWh of active energy consumed in various energy tariff zones was distinguished. In the next step, these data were compared with the information about the actual operating time of the pumps, which made it possible to identify the actual energy consumption for the pumping process, ignoring other consumption costs, such as heating or lighting. Due to data gaps, 38 drainage pumping stations were finally considered. The economic efficiency of the tariff change was assessed using the current value, i.e., for the year 2021.

Table 2. Details of the analyzed drainage pumping stations according to WZMiUW.

Districts of WZMiUW	Pumping Stations	$Q_{\sum}$ (m^3/s)	$Fp_{\sum}$ (ha)	$P_{\sum}$ (kW)
KONIN	11	35.2	42,609	2477
POZNAŃ	12	12.4	7544	836
LESZNO	12	13.0	7477	753
PIŁA	4	5.5	2231	484
OSTRÓW WLKP	1	1.6	264	82

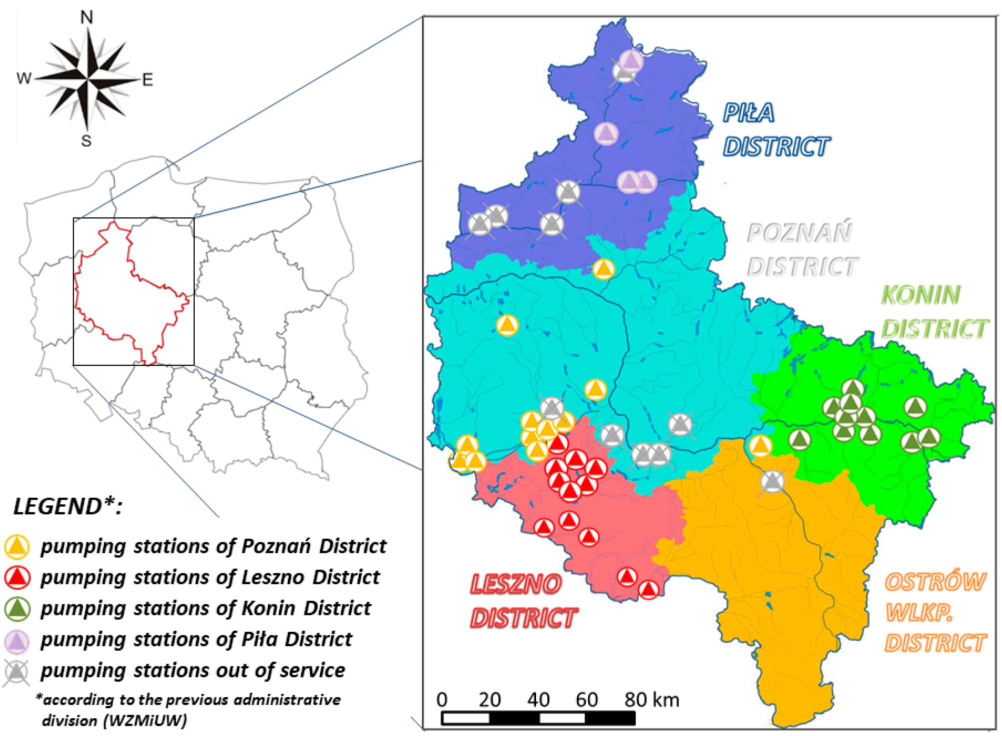

Figure 2. Drainage pumping stations in Greater Poland Voivodeship, administered by WZMiUW (currently by RZGW).

The energy consumption in the remaining years was taken as average values from the research period, including the increase in energy costs, according to Grycan [34]. To make the costs comparable, the future value method (*FV*) was used, which transfers all the costs during the project time to a base year: Equation (1).

$$FV = PV \cdot p_t, \quad (1)$$

where:

FV is the future value, which transfers all the cost from the past to the base year (2021);
PV is the present value or current value of the future of energy savings;
p_t is the interest factor, which is described by Equation (2):

$$p_t = (1 + r)^t \quad (2)$$

where:

r is the interest rate (nominal);
t is the number of years.

The interest factor (p_t) allows determining the final value for the years proceeding the base year. The interest rates (*r*) for the analyzed years were adopted based on reference and discount rates from the National Bank of Poland (NBP) and calculated in accordance with the communication from [35]. The inflation for the analyzed period was taken from Statistics Poland [4]. Real interest rates were calculated using The Fisher Equation (3):

$$rr = \frac{(1+r)}{(1+i)} - 1 \quad (3)$$

where:

rr is the real interest rate;
r is the nominal interest rate;
i is the inflation rate.

Two groups of energy tariffs were analyzed in this study. In general, they can be divided into two types:

- fixed tariffs (in this work called 24 h tariffs);
- time of use (TOU) tariffs (often named multi-zone or multi-part tariffs).

TOU tariffs have emerged as one of the most common approaches adopted by utility companies to achieve more efficient and effective demand management. A TOU tariff establishes differing rates for electricity consumption during different periods of the day [36]. Generally, there are two or three periods during a day: on-peak, off-peak, and, in some cases, mid-peak hours. Among the analyzed tariffs from the first group, the following tariffs were taken into account: B11, C1, and C21, and from the remaining groups, tariffs B21, B22, C12a, and C22a. Electricity prices and analyzed tariff plans are shown in Figure 3.

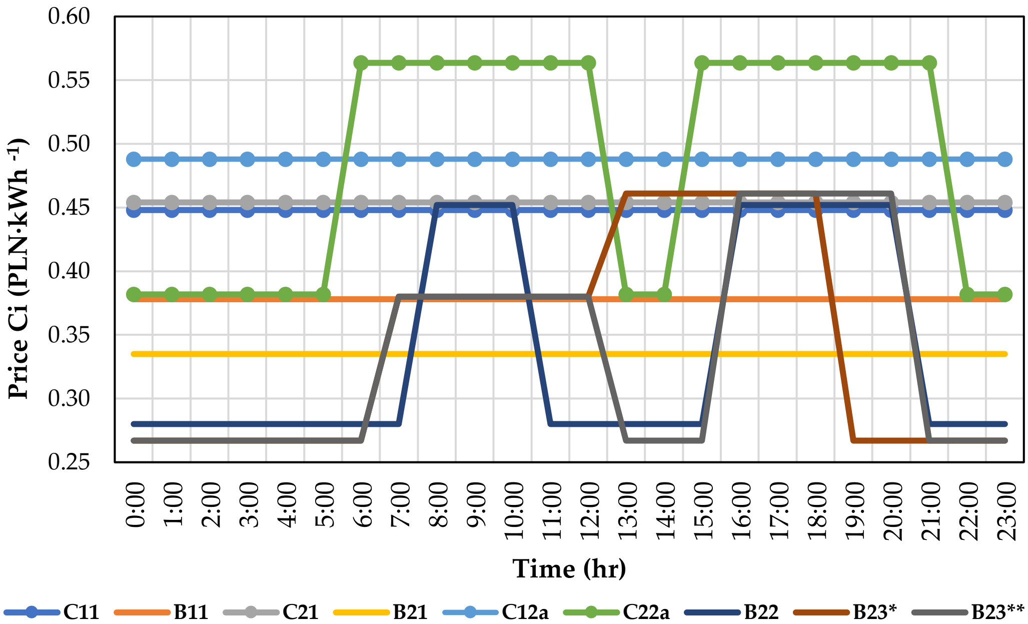

Figure 3. Electricity prices in analyzed tariff plans (1PLN~ 0,22€). B23* and B23** indicate the tariff plan for spring and fall - winter.

3.2. Hydro-Meteorological Conditions and Their Influence on Pumping Stations' Work

Hydro-meteorological variables have an impact on pumping work, where the most important impacts are radiation, temperature, rainfall, and water levels. According to the Köppen-Geiger classification [37], the local climate of Poland is Dfb, a warm temperature subtype of humid continental climate also known as a hemiboreal climate found in much of Eastern Europe and the south and central parts of Scandinavia. The average annual precipitation (1989–2018) from the nearest meteorological station, Poznań (52°25′ N, 16°55′ E) [38], is 523 mm and mostly concentrated in the summer (June–August). The value corresponds to the most arid regions of Europe [39]. Sixty percent (330 mm) of the average annual precipitation occurs during the growing season (April–September). During the analyzed period (2010–2013), the annual precipitation, depending on the district and year, fluctuated widely (Figure 4). The analyzed period was exceptional in terms of the conducted research period. The year 2010 was clearly wet. At this time, one of the largest floods occurred in Central Europe, including Poland, as a result of heavy rainfall. Whereas the following year, 2011, was a period of drought. According to [40], in total, about 4% of the Greater Poland Voivodeship is covered by flood-risk areas. Half of this area is serviced by the analyzed drainage pumping stations.

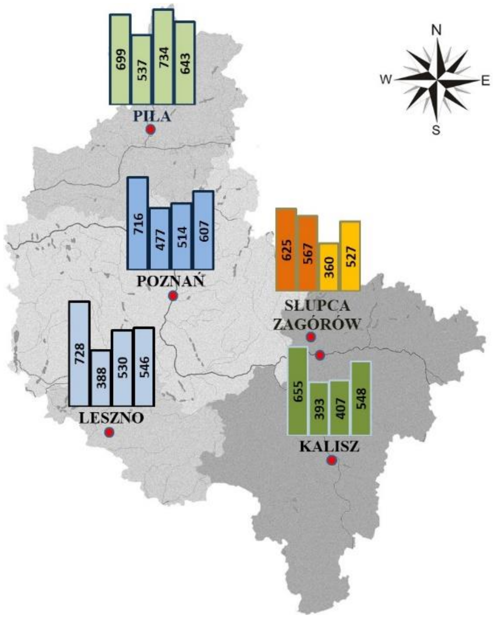

Figure 4. Annual precipitation in the analyzed years 2010–2013, according to specific districts of WZMiUW.

The year 2011 was an average (Piła) or dry year. Within the analyzed districts, the following years were quite varied. According to [41], Greater Poland is in the region with the lowest precipitation in Poland. This region is also characterized by a high coefficient of variation (CV) of precipitation (up to 250%). Moreover, researchers found that in the last 50 years, in this part of Poland, there have been periods when the sum of precipitation during the season (IV–IX) was smaller than average by half and sometimes more (e.g., in 1989, precipitation was only 113 mm, and in 1992 160 mm). The drainage pumping station is an extensive system of supply channels, whereby efficiency determines the pump's operation. In flat valleys, keeping the minimum speed to avoid overgrowth and siltation of water beds is often a problem [42]. The water level, which should be no less than 20–30 cm, also influences the overgrowth of channels [43]. According to [44], even slight channel overgrowth with water vegetation on the bottom and slopes, especially in small watercourses and drainage canals, can significantly affect channel capacity. Due to the difficulties maintaining necessary water velocities in watercourses, increased maintenance works should also be taken into account. The operational problems of drainage devices have gained importance, especially after the fourth report on climate change [45]. The projections indicated therein suggest growth in intense rainfall, especially in summer periods, and, thus, an increased risk of flooding [46]. As emphasized by Van Overloop [47], gradually increasing weather anomalies and more frequent inflows to the pumping station, also caused by urbanization, should be corrected not by a gradual increase in the efficiency of the pumps, but by an appropriate operating philosophy, referred to as "First retain, then store, only then discharge ". The description of the dynamics of water level changes in open channels as a result of the impact of the operation of pumps is complex. There are methods for a mathematical description of these phenomena, e.g., based on De Saint Venant differential equations [48]. However, the solution of these equations requires knowledge of many different parameters, which are difficult to obtain. Further, some of them depend on time. With the change of seasons, the hydraulic parameters of the canals change significantly [49,50]. The variability of water levels in the supply channel is satisfactorily described by models using neural networks, which was confirmed by experimental studies [47,51,52].

3.3. Energy Cost Calculation

The monthly fee for electricity consumption is calculated from Formula 4 in accordance with the ordinance of the Minister of Energy [22]:

$$O_{poi} = \sum_{k=1}^{r} C_i \cdot E_{pik} + S_{SVn} \cdot P_i + \sum_{k=1}^{r} S_{ZVnk} \cdot E_{pik} + S_{oSJ} \cdot E_{ok} + S_{op} \cdot P_i + O_a \tag{4}$$

where:

O_{poi} is the payment for electricity and distribution services (PLN);
Ci is the electricity price in a given time zone k (PLN·kWh^{-1});
S_{SVn} is the fixed component of the grid rate (PLN·kW^{-1}·miesiąc^{-1});
Pi is the contracted capacity (kW);
S_{ZVnk} is the variable component of the network rate for the time zone k (PLN·kWh^{-1});
$Epik$ is the amount of energy taken from the grid, in the time zone k (kWh);
r is the number of time zones.

Based on the analysis of 1.870 electricity invoices for individual pumping stations, certain common energy billing costs were identified. These costs are divided into three groups:

- fixed costs, independent of the amount of energy consumed and contracted capacity;
- variable costs, depending on the amount of active energy consumed;
- fixed costs, depending on the amount of contracted capacity.

Based on this information, it was possible to simplify Formula 4 to the following form (Equation (5)):

$$O_{poi(MOD)} = A + B \cdot E_{pik} + C \cdot P_i \tag{5}$$

where:

$O_{poi(MOD)}$ is the payment for electricity and distribution services (PLN);
A is the fixed costs independent of the amount of energy consumed and contracted capacity (PLN);
E_{pik} is the amount of energy taken from the grid, in the time zone k (kWh);
B is the variable costs, depending on the amount of active energy consumed, (PLN·kWh^{-1});
C is the fixed costs, depending on the amount of contracted capacity (PLN·kW^{-1}).

The proposed modification, Equation (5), does not take into account the costs of reactive energy and other expenses related to specific situations, e.g., exceeding the contracted capacity. The author has adopted the principle that in optimized pumping systems, these costs do not occur or are of little value in relation to the total.

3.4. Energy Charges at Different Zone Tariffs—Profitability Ratios (PR)

One of the most important criteria for assessing the efficiency of water management in pumping stations is the unit cost of electricity [11]. The average tariff price of energy may be regarded as one of the measures for assessing the recipient's electricity economy, in particular, if that recipient is an industrial plant. Therefore, the natural process is to minimize these costs (Equation (6)):

$$E = \frac{C}{A} \text{ where } C, E \rightarrow \min \tag{6}$$

where:

E is the average unit price (expenditure) for consumed active energy (PLN·kWh^{-1});
C is the cost of active energy (PLN);
A is the amount of active energy consumed (kWh).

These goals can be achieved by:

- changing the tariff and minimizing the average rate of charges for the consumed active energy;
- optimizing the contracted capacity (*Pi*).

The average unit price (P) for the collected active energy (A) depends on the distribution of energy consumption in different time zones during the day. Therefore, in order to compare the profitability of changing the tariff from single-zone to multi-zone and vice versa, the profitability index was determined. It is expressed in relative units, i.e., in relation to the 24 h active energy rate (*STc*) and can be calculated using Equations (7)–(9):

- One-zone tariff (24 h):

$$PR_I = \frac{P}{ST_C} = 1 \tag{7}$$

- Two-zone tariff:

$$PR_{II} = EI_{II} + \alpha_{peak} \cdot (EI_I - EI_{II}) \tag{8}$$

- Multi-zone tariff:

$$PR_{III} = EI_{III} + \alpha_{peak} \cdot (EI_I - EI_{III}) + \alpha_{off-peak} \cdot (EI_{II} - EI_{III}) \tag{9}$$

where:

$PR_{I,II,III}$ is the relative value of the profitability ratio index in tariffs (-);
P is the average price for active energy (PLN·kWh^{-1});
STc is the energy rate at a 24 h tariff zone taking into account additional charges related to the energy consumed, i.e., network and industry charges (PLN·kWh^{-1});
ST_I is the energy rate at tariff zone I, taking into account additional charges related to the energy consumed, i.e., network and industry charges (PLN·kWh^{-1});
ST_{II} is the energy rate at tariff zone II, taking into account additional charges related to the energy consumed, i.e., network and industry charges (PLN·kWh^{-1});
ST_{III} is the energy rate at tariff zone III, taking into account additional charges related to the energy consumed, i.e., network and industry charges (PLN·kWh^{-1});
EI_I is the amount of peak energy (at tariff zone I) in relation to the 24 h rate (ST_I/STc) (-);
EI_{II} is the amount of off-peak energy ratio in relation to the 24 h rate (ST_{II}/STc) (-);
EI_{III} is the amount of energy expressed as an indicator of the energy in the remaining hours in relation to the daily rate (ST_{III}/STc) (-);
α_{peak} is the share of energy consumed in the peak zone (-);
$\alpha_{offpeak}$ is the share of energy consumed in the off-peak zone (-).

By knowing the operating times and energy consumption of the drainage pumps, it was possible to determine when a tariff change was more beneficial. The profitability of a given multi-zone tariff in relation to the 24 h tariff is determined by the values of the PR_{II} and PR_{III} profitability ratios. The lower, the better. In practice, this means that a new tariff is financially more favourable than the current one. For the analyzed drainage pumping stations, only tariffs from groups B and C and from two distribution system operators (DSO), ENEA and ENERGA, were taken into account. The presented profitability ratios (PR) make sense only when the fixed costs in a given tariff are at a similar level. Therefore, their application is usually limited to tariffs from the same group.

4. Results

Profitability from Changing Energy Tariffs

Based on the analysis of electricity consumption from the bills of a four-year research period, the profitability and validity of using a multi-part tariff were determined. The results of these analyses are presented in the form of a PR (Figure 5). As demonstrated, the change of the single-zone tariff did not bring satisfactory results everywhere. This was the case, for example, at the Wonieść and Antonina pumping stations. The common feature of both facilities is that they cooperate with large reservoirs. As indicated by the operation time of these facilities, these pumps operate for most of the day. A change to a different tariff would, therefore, be unjustified here. Further analysis revealed a significant impact on the contracted capacity and sense of applying a new tariff. In large facilities, such as Wola Podłężna, where six pump units with a total power of 670 kW (2 × 105 kW + 4 × 125 kW) are operating, the contracted capacity is 200 kW. This means that only one pump can work at a time. This is because this pumping station and all the others in the Konin region are typical polder pumping stations. The operation of such facilities is relatively rare, mainly in periods of high water levels and in the event of excessive depression, preventing the free outflow of water from the polder. Ordering the capacity for all pump sets would be pointless as it would involve huge fixed fees. In Figure 6, the profitability of changing tariffs in relation to the ratio of the amount of electricity consumed to the contracted capacity was shown. The research shows that the most advantageous transition is from tariff C21 to B23. For example, using TOU at a pumping station with a contracted capacity of 100 kW is justified after consuming 700 kWh energy. If tariff B21 is changed to B22 or B21 to B23, the profitability threshold (at 100 kW contracted capacity) is exceeded after 1070 and 1290 kWh are consumed. Changing tariff C21 to C22a was the least profitable, or rather, the riskiest. With the ordered capacity equal to 100 kW, the new tariff becomes profitable only after exceeding 3400 kWh per month, which is not possible in the case of many facilities. When using tariffs with a connection capacity of at least 40 kW, the operating time in relation to the ordered capacity is also related and decreases with the increase of time worked. Referring to the obtained results, it should be noted that although all pumping stations are drainage pumping stations, each of the facilities has a different specificity of operation. As already mentioned, the pumping stations operating in the Konin district are mainly levee pumping stations operating along the Warta River. All analyzed facilities from this region operate under TOU tariffs. Therefore, it was difficult to achieve greater quantitative savings in this region. On average, a 3% of cost reduction was achieved at these facilities (Figure 7). The research shows that the greatest financial effects would be achieved here by changing tariff C22a to B22. According to Nowicki and Bate [53], if it is possible to choose a tariff from two other groups, it is worth using this higher tariff group. The pumping stations of the Poznań and Leszno districts are mainly smaller pumping stations located on watercourses and drainage canals. In the case of Poznań, many of these pumping stations are obsolete and require modernization. On the other hand, the pumping stations in the Leszno district are modernized and have new facilities. Some of these pumping stations, like Wonieść, function as reservoir pumping stations. The work of these pumping stations operates similarly to water distribution systems based on the work of the retention tanks. Pumps at such facilities operate in accordance with a specific pumping schedule. As a result, in most cases, changing the existing tariff does not make sense. Savings here were the lowest and amounted to only 1%. The biggest savings were made in Piła (19%). Unfortunately, this concerned only two drainage pumping stations.

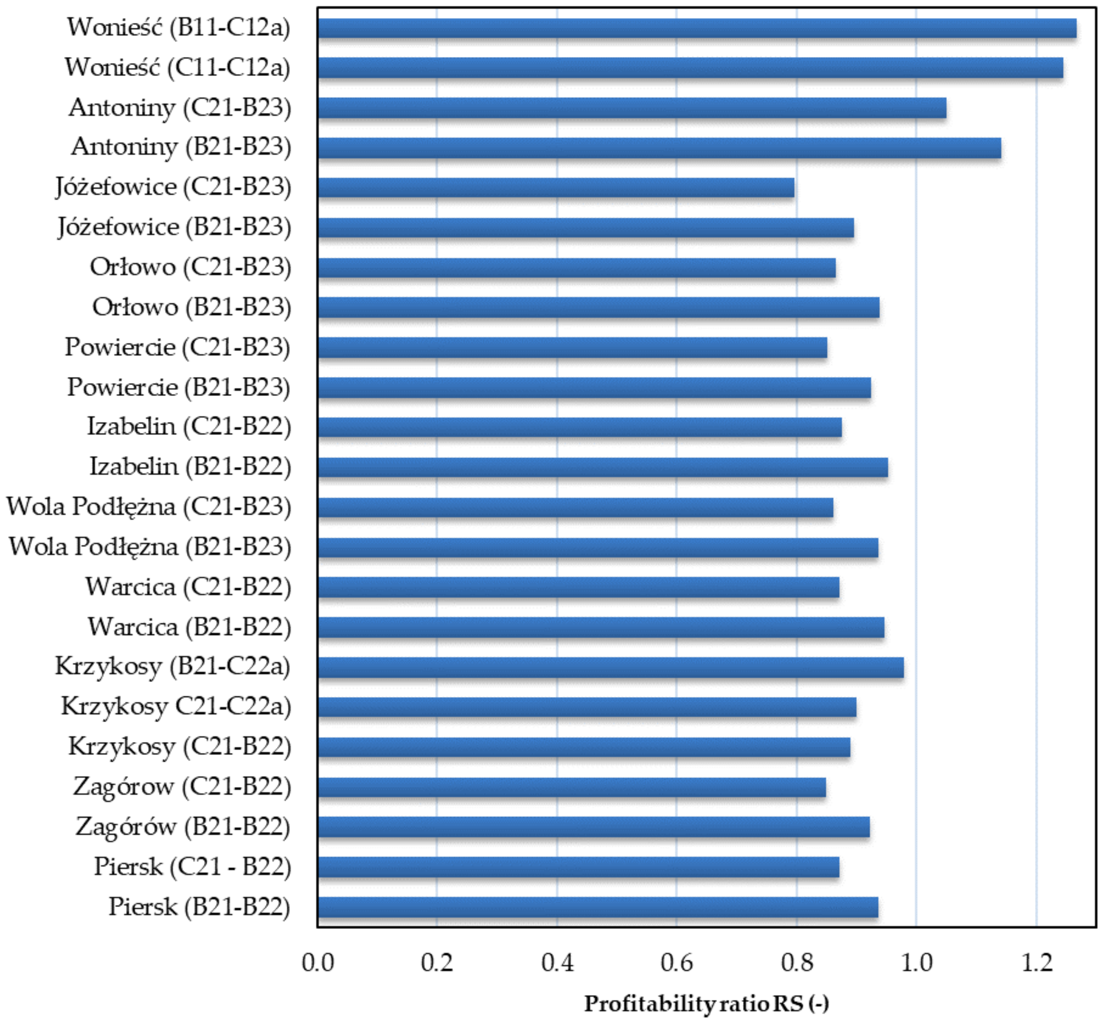

Figure 5. Profitability ratios (PR) of exemplary drainage pumping stations.

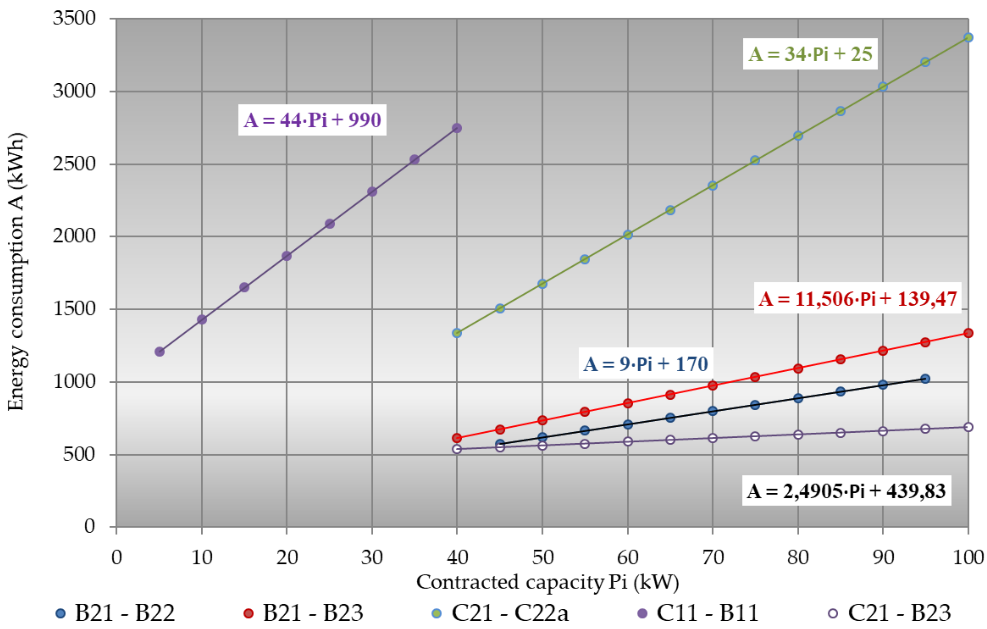

Figure 6. Breakeven of energy tariff change depending on the level of contracted capacity (Pi (kW)) and monthly energy consumption (A (kWh)).

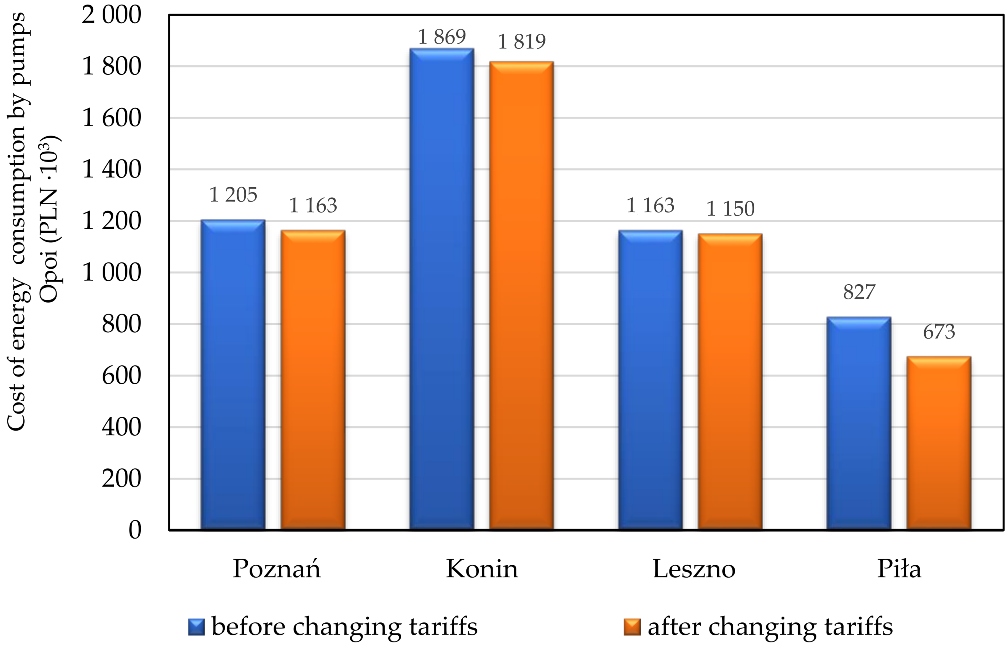

Figure 7. Average yearly cost of pump energy consumption (in PLN~0.22 €) before and after tariff change, achieved during the four-year research period.

On average, 5% savings were achieved for all analyzed pumping stations (Figure 7). This is a significant amount considering the fact that these effects were obtained for free by changing the contract with the energy operator. In the analyzed four-year period, it was estimated that these savings could amount to almost PLN 0.5 million (EUR~110,000), and by 2021 these savings could even amount to PLN 1.7 million (EUR~374,000), as shown in Table 3.

Table 3. Savings (in PLN~0.22 €) resulting from changes in tariffs on the analyzed facilities according to the previous administrative division of WZMiUW (the forecast years are marked in italics).

Districts of WZMiUW	2010–2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Poznań	156,251	40,781	42,576	44,449	46,405	48,447	50,578	52,804	55,127	537,418
Konin	134,341	35,063	36,606	38,216	39,898	41,653	43,486	45,399	47,397	462,059
Leszno	161,576	42,171	44,027	45,964	47,986	50,098	52,302	54,603	57,006	555,733
Piła	42,408	11,068	11,555	12,064	12,595	13,149	13,727	14,331	14,962	145,859
TOTAL:	494,575	129,084	134,764	140,693	146,884	153,347	160,094	167,138	174,492	1,701,070

As a result, it would be possible to finance the modernization of one of the pumping stations. The savings from the change of tariffs were presented against the background of the administrative division, updating the obtained values from 2021 (11 years), assuming, according to methodology, the value of the capitalization rate and the annual increase in energy prices was 2% [34].

5. Discussion

Operational costs are related to the energy consumption of the pumping stations, which are mainly determined by the power consumed by the pumps. To minimize the electricity cost of the pump station, electricity consumption needs to shift from peak time to off-peak or standard time as far as possible. Comprehensive scientific research about optimizing pumping operations has been published since the 1970s [54]. Moreover, the study [55] revealed that pump operation optimization is one of the two major areas of optimization research. However, existing studies are mainly related to WDSs' (water distribution systems) energy efficiency improvements. Approximately 2–3% of the world's electrical energy is used for water supply and sanitation purposes, and 1–18% of the electrical energy in urban areas is used to treat and transport water and wastewater [56]. According to [57], the intensive cost of establishing a new pumping station and the ever-increasing cost of energy has caused us to pay more attention to the optimal design and operation of drainage pumping stations. This shows that the savings in irrigation may be significant.

In the case of WDSs, suitable pump scheduling is more predictable and manageable due to constant water distribution. Further, WDSs are critical infrastructure for modern cities; therefore, minimizing pumping energy costs is crucial for all customers. There are many studies about optimizing pumps based on deterministic approaches, such as dynamic programming (DP) [58], linear programming (LP) [59,60], non-linear programming (NLP) [61], and mixed-integer non-linear programming (MINLP) [62]. Recently, meta-heuristic algorithms, such as genetic algorithms [63], simulated annealing [64], and particle swarm optimization [65], have been used for finding open-loop schedules for pump operations. However, these studies are based on a constant work pattern that did not consider real-time pump operations and should not be used for future decision-making. As indicated by [66], an alternative to these solutions can be model predictive control (MPC). This is another way to solve the operational problem of water management, but it needs measurements of the current system state to make informed decisions in real-time. In the case of drainage pumping stations, the problems are more complex. The drainage pumping system comprises not only the pump units but the entire catchment area. Such a system is largely inertial and requires obtaining much information from the outside (about rainfall, temperature, water level, etc.). Provided in advance, inflows make it possible to maintain a constant water damming height at the pumping station, positively influencing the operation of the pumps [47]. The study shows that using MPC to control the Dutch water system can result in a cost reduction of EUR 200,000 per year. However, this system is strictly dependent on the tides.

Due to the lack of sufficient data and their quality for predictive modeling, this paper was limited to the analysis of generally available information, mainly focusing on energy bills. In this study, a simple model of comparing the profitability of using multi-zone tariffs in relation to single-zone tariffs was performed. Moreover, a simplified model of calculating the price for the consumed energy has been presented. It turns out that the choice of a given tariff is determined not only by the amount of energy consumed but also by contracted capacity. This value, in turn, determines the profitability of the selected tariff, making it dependent on the amount of energy consumed. [67] also mentions the problems of calculating energy costs, demonstrating that electricity price in Poland has more than ten components. Understandably, most users are not able to assess the real cost of electricity by reading their bills. Only some know that they can change just one of the components (that is about 35% of the final price), and the others are mostly tax, independent of their use. [13] further confirmed that the TOU tariff is one of the key strategies of load shifting (LS). In this way, they reduced the energy costs of pumping by as much as 60%. The study by [68] concludes that even small shifts in peak demand would have a large effect on savings to consumers and avoid costs for additional peak capacity: a 1% shift in peak power demand would result in savings of 3.9%. [69] endeavour to minimize the pumping energy costs to ensure that the water level in an elevated tank rests at its minimum and maximum values at the end of the peak and off-peak tariff periods, respectively (this is also called the level-triggered method). However, for some drainage pumping stations that operate on canals, this water management system would not be possible due to the lack of a reservoir. Another example of the results of changing tariff rates is the study conducted by [70], which shows that a selection of the C12a rate group at a sewage treatment plant is economically justified due to the pumps working for about 25% of the time at peak hours. In this case, it was possible to decrease the annual cost of energy by 12%. The observations of [71] show that while TOU tariffs can provide users with an opportunity to cut costs by shifting their consumption to hours with lower rates, they can also be unfavourable for the environment.

Such shifts may increase carbon emissions for regions that use coal-fired generation to meet the baseload electricity demand. This is because coal-fired generation plants normally have a greater carbon footprint per kWh of electricity produced than gas-fired generation plants. In this context, shifting electricity usage from on-peak hours to off-peak or mid-peak can reduce the total electricity cost of manufacturing enterprises with a trade-off of an increased carbon footprint.

6. Conclusions

This article shows how important it is to choose the right tariff when optimizing your pumping process. The research shows that even in the absence of proper monitoring of the pumps' operation (mostly paper logs) and mainly based on data from bills, it was possible to achieve savings. It is worth adding that this money invested in the monitoring system (level water loggers and meteorological weather stations) will bring further measurable savings. Using accurate data, the operation of pumps can be anticipated and planned. It should be noted that drainage pumping stations have been gradually modernized since 2010. One of the main effects of these activities is the replacement of old pumps with new ones, mainly submersible. As a result, the new pump units achieve the same hydraulic parameters as the old ones, with a much lower demand for engine power. Therefore, reducing contracted capacity by the value of the difference between new and "old" pumps may bring additional measurable benefits. To summarize, when analyzing the choice of tariffs for drainage pumping stations, attention should be paid to:

- the amount of energy used in the process of pumping water and the amount of energy used for purposes related to the general operation of the pumping station (lighting, heating, etc.);
- the power of the largest pump unit, which affects the level of contracted capacity and, thus, increases costs;
- the conditions of water inflow to the pumping station, specifying the number and frequency of starts (the larger the inlet tank, the greater the possibility of adjusting the pump operation to off-peak hours).

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References

1. Abdelaziz, E.A.; Saidur, R.; Mekhilef, S. A review on energy saving strategies in industrial sector. *Renew. Sustain. Energy Rev.* **2011**, *15*, 150–168. [CrossRef]
2. Shankar, V.K.A.; Umashankar, S.; Paramasivam, S.; Hanigovszki, N. A comprehensive review on energy efficiency enhancement initiatives in centrifugal pumping system. *Appl. Energy* **2016**, *181*, 495–513. [CrossRef]
3. U.S. Energy Information Administration. International Energy Outlook 2021. Available online: https://www.eia.gov/outlooks/ieo/ (accessed on 1 September 2021).
4. GUS; Statistics Poland. Local Data Bank. Available online: https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica (accessed on 7 November 2021).
5. Jędral, W. Res and energy efficiency in context of challenges for electricity generation and utilization on energy in Poland. *Rynek Energii* **2019**, *5*, 144–156.
6. Waide, P.; Brunner, C. *Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems*; IEA Energy Papers 2011/07; OECD Publishing: Paris, France, 2011; pp. 1–132. [CrossRef]

7. European Commission (EC). Study on Improving the Energy Efficiency of Pumps. 2001. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjMvu7V2bT1AhXsiIsKHfmQCNcQFnoECAQQAQ&url=https%3A%2F%2Fwww.jacobalbertsen.dk%2Fkomposit%2FDarmstadtrapport.pdf&usg=AOvVaw0vhrRGFmmscPTYFA667sRO (accessed on 1 September 2021).
8. Hovstadious, G. *Industrial Energy Efficiency Project: Pump Systems Optimization—End User Training*; United Nations Industrial Development Organization: Cape Town, South Africa, 2012.
9. Waghmode, L.Y.; Birajdar, R.S.; Joshi, S.G. a life cycle cost analysis approach for selection of a typical heavy usage multistage centrifugal pump. In Proceedings of the 8th Biennial ASME Conference on Engineering Systems Design and Analysis, Torino, Italy, 4–7 July 2006; Volume 2, pp. 865–873. [CrossRef]
10. Kim, M.; Choi, T.; Kim, M.; Han, S.; Koo, J. Optimal operation efficiency and control of water pumps in multiple water reservoir system: Case study in Korea. *Water Sci. Technol. Water Supply* **2015**, *15*, 59–65. [CrossRef]
11. Augustyn, T. Energy efficiency and savings in pumping systems—The holistic approach. In Proceedings of the Southern African Energy Efficiency Convention (SAEEC), Johannesburg, South Africa, 14–15 November 2012; pp. 1–7. [CrossRef]
12. Bykowski, J.; Napierała, M.; Przybyła, C. Energy efficiency assessment of retrofits' land reclamation pumping stations. *Annu. Set Environ. Prot.* **2015**, *17*, 1413–1427.
13. Zheng, G.; Huang, Q. Energy optimization study of rural deep well two-stage water supply pumping station. *IEEE Trans. Control Syst. Technol.* **2015**, *24*, 1308–1316. [CrossRef]
14. Napierala, M.; Bykowski, J. Approach to divide of land reclamation pumping stations work at polder areas. *Wiadomości Melior. Łąkarskie* **2017**, *60*, 73–78.
15. NRP. National Report of President of ERO. 2019. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiE5KXIttr0AhXuAhAIHVWaAwUQFnoECCMQAQ&url=https%3A%2F%2Fwww.ure.gov.pl%2Fdownload%2F2%2F478%2FNationalReport2019.pdf&usg=AOvVaw3nOHRmgOr-rF2YMVPiOENI (accessed on 1 September 2021).
16. Energy Law from April 10, 1997 (Journal of Laws No. 54, Item 348, as Amended). Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU19970540348/U/D19970348Lj.pdf (accessed on 1 September 2021).
17. Minister of Economy. The Energy Policy of Poland until 2030, M.P. *Monit. Pol.* **2010**, *2*, 27–149. Available online: http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WMP20100020011 (accessed on 7 December 2021).
18. Ministry of Climate and Environment (MCE). Energy Policy of Poland until 2040. Available online: https://www.gov.pl/web/klimat/polityka-energetyczna-polski (accessed on 7 December 2021).
19. Eurlex. European Union Legislation. Available online: https://eur-lex.europa.eu/summary/chapter/18.html?expand=1807#arrow_1807 (accessed on 7 December 2021).
20. Nafkha, R.; Gajowniczek, K.; Ząbkowski, T. Do Customers Choose Proper Tariff? Empirical Analysis Based on Polish Data Using Unsupervised Techniques. *Energies* **2018**, *11*, 514. [CrossRef]
21. European Parliament (EP). DIRECTIVE (EU) 2018/2002 on energy efficiency. *Off. J. Eur.* **2018**, *328*, 210–230. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.328.01.0210.01.ENG (accessed on 6 December 2021).
22. Tariff Regulation (TR). Regulation of the Minister of Energy of March 6, 2019, on Detailed Rules for the Formation and Calculation of Tariffs and Settlements in Trading in Electricity, Dz.U. 2019 poz. 503. Available online: http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190000503 (accessed on 6 December 2021).
23. Szydło, R.; Wiśniewska, S.; Tyrańska, M.; Dolot, A.; Bukowska, U.; Koczyński, M. Employer Expectations Regarding the Competencies of Employees on the Energy Market in Poland. *Energies* **2021**, *14*, 7233. [CrossRef]
24. Grycan, W. Legislative support for improving sustainable and smart electricity consumption in polish residential sector. *J. Clean. Prod.* **2020**, *266*, 121995. [CrossRef]
25. Ghani, G.M. Does trade liberalization effect energy consumption? *Energy* **2012**, *43*, 285–290. [CrossRef]
26. Rys, M.; Wilczynski, A. Examination of energy tariffs efficiency impact on energy demand. *Electr. Rev.* **2006**, *82*, 82–83.
27. Billewicz, K. Effectiveness of DSR—Between stimulus and response. *Przegląd Elektrotechniczny* **2012**, *88*, 308–314.
28. Weron, R. Electricity price forecasting: A review of the state-of-the-art with a look into the future. *Int. J. Forecast.* **2014**, *30*, 1030–1081. [CrossRef]
29. Kowalska-Pyzalska, A.; Maciejowska, K.; Suszczynski, K.; Sznajd-Weron, K.; Weron, R. Turning green: Agent-based modeling of the adoption of dynamic electricity tariffs. *Energy Policy* **2014**, *72*, 164–174. [CrossRef]
30. Aymerich, I.; Rieger, L.; Sobhani, R.; Rosso, D.; Corominas, L. The Difference Between Energy Consumption and Energy Cost: Modelling Energy Tariff Structures for Water Resource Recovery Facilities. *Water Res.* **2015**, *81*, 113–123. [CrossRef]
31. Water Law (WL). Internet System of Legal Acts. Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170001566 (accessed on 5 December 2021).
32. Central Statistical Office (CSO). *Statistical Yearbook of Agriculture. Branch Yearbooks*; Central Statistical Office: Warsaw, Poland, 2014; p. 445. Available online: https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystyczny-rolnictwa-2014,6,8.html (accessed on 7 December 2021).
33. Napierala, M.; Bykowski, J.; Przybyla, C.; Mrozik, K. Functioning of low lift pumping stations on polders—A case study of Zagorow, Poland. *FEB Fresenius Env. Bull.* **2018**, *27*, 6598–6609.

34. Grycan, W. Energy efficiency improvement—A case study of electricity consumption in polish households. In Proceedings of the 2019 4th International Conference on Smart and Sustainable Technologies (SpliTech), Split, Croatia, 18–21 June 2019; pp. 1–5. Available online: https://ieeexplore.ieee.org/abstract/document/8783192 (accessed on 26 October 2021).
35. European Commission (EC). Communication from the Commission on the Revision of the Method for Setting the Reference and Discount Rates. OJ C 14, 19.1.2008. pp. 6–9. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52008XC0119%2801%29 (accessed on 5 December 2021).
36. Cousins, T. Using time of use (TOU) tariffs in industrial, commercial and residential applications effectively. *TLC Eng. Solut.* **2009**. Available online: http://www.tlc.co.za/white_papers/pdf/using_time_of_use_tariffs_in_industrial_commercial_and_residential_applications_effectively.pdf (accessed on 5 December 2021).
37. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z.* **2006**, *15*, 259–263. [CrossRef]
38. World Meteorological Organization (WMO). World Weather Information Service. Available online: https://worldweather.wmo.int/en/city.html?cityId=26 (accessed on 3 December 2021).
39. Mrozik, K. Assessment of Retention Potential Changes as an Eslement of Suburbanization Monitoring on Example of an Ungauged Catchment in Poznan Metropolitan Area (Poland). *Annu. Set Environ. Prot.* **2016**, *18*, 188–200.
40. Mrozik, K. The Impact of Soil Cultivations Methods on Retention Capacity of Kania Rriver Basin. *Wasserwirtschaft* **2012**, *102*, 75–79. [CrossRef]
41. Łabędzki, L.; Ostrowski, J. Precipitation Preventing a Deficit of Readily Available Soil Water in Arable Soils in Poland. *Atmosphere* **2018**, *9*, 121. [CrossRef]
42. Van der Molen, W.H.; Beltrán, J.M.; Ochs, W.J. *Guidelines and Computer Programs for the Planning and Design of Land Drainage Systems*; FAO Irrigation and Drainage Paper 62; FAO: Rome, Italy, 2007; p. 250.
43. Smedema, L.K.; Vlotman, W.F.; Rycroft, D.V. *Modern Land Drainage: Planning and Management of Agricultural Drainage Systems*; CRC Press: London, UK, 2004.
44. Walczak, N.; Hammerling, M.; Bykowski, J.; Walczak, Z. Economic and Hydraulic Criteria for Maintenance of Good Condition of Drainage Ditches. *J. Agribus. Rural Dev.* **2015**, *35*, 137–146. [CrossRef]
45. IPPC. *Zmiana Klimatu. Raport Syntetyczny. Wkład Grup Roboczych I, II, III do Czwartego Raportu Oceniającego Międzyrządowego Zespołu ds. Zmian Klimatu*; Wyd. IOŚ: Warsaw, Poland, 2009; p. 112. (In Polish)
46. Starkel, L.; Kundzewicz, Z.W. Consequences of climate change for spatial organization of Poland. *Nauka* **2008**, *1*, 103–118.
47. Van Overloop, P. *Model Predictive Control on Open Water Systems*; Delft University Press: Delft, The Netherlands, 2006; p. 192.
48. Van Overloop, P.J. Drainage control in water management of polders in the Netherlands. *Irrig. Drain. Syst.* **2006**, *20*, 99–109. [CrossRef]
49. Van Zuidam, B.G. Modeling the Seasonal Change of Aquatic Vegetation in Ditches. Master's Thesis, Wageningen University, Wageningen, The Netherlands, 2009.
50. Walczak, N.; Walczak, Z.; Hämmerling, M.; Przedwojski, B. Analytical Model for Vertical Velocity Distribution and Hydraulic Roughness at the Flow Through River Bed and Valley with Vegetation. *Annu. Set Environ. Prot.* **2013**, *15*, 405–419.
51. Van Overloop, P.; Schuurmans, J.; Brouwer, R.; Burt, C.M. Multiple-Model Optimization of Proportional Integral Controllers on Canals. *J. Irrig. Drain Eng.* **2005**, *131*, 190–196. [CrossRef]
52. Baghlani, A. Optimal Control of Pumping Station in Open Channels by Metaheuristic Firefly Algorithm. *Int. J. Optim. Civ. Eng.* **2012**, *2*, 369–382.
53. Nowicki, R.; Bate, M. An Intelligent Approach to Anomaly Detection at Work of Machines Driven by Electric Motors. *Masz. Elektr. Zesz. Probl.* **2013**, *2*, 241–246.
54. Mala-Jetmarova, H.; Sultanova, N.; Savic, D. Lost in optimisation of water distribution systems? A literature review of system operation. *Environ. Model. Softw.* **2017**, *93*, 209–254. [CrossRef]
55. Wang, Y.; Too Yok, K.; Wu, W.; Simpson, A.R.; Weyer, E.; Manzie, C. Minimizing Pumping Energy Cost in Real-Time Operations of Water Distribution Systems Using Economic Model Predictive Control. *J. Water Resour. Plan. Manag.* **2021**, *147*, 04021042. [CrossRef]
56. Olsson, G. *Water and Energy: Threats and Opportunities*; IWA Publishing: London, UK, 2002.
57. Moradi-Jalal, M.; Mariño, M.A.; Afshar, A. Optimal design and operation of irrigation pumping stations. *J. Irrig. Drain. Eng.* **2003**, *129*, 149–154. [CrossRef]
58. Sterling, M.; Coulbeck, B. A dynamic programming solution to optimization of pumping costs. *Proc. Inst. Civ. Eng.* **1975**, *59*, 813–818.
59. Giacomello, C.; Kapelan, Z.; Nicolini, M. Fast hybrid optimization method for effective pump scheduling. *J. Water Resour. Plan. Manag.* **2013**, *139*, 175–183. [CrossRef]
60. Kurian, V.; Narasimhan, S.; Narasimhan, S. Optimal scheduling of rural water supply schemes. In Proceedings of the 5th IFAC Conference on Advances in Control and Optimization of Dynamical Systems (ACODS), Hyderabad, India, 18–22 February 2018; pp. 142–147.
61. Ormsbee, L.E.; Reddy, S.L. Nonlinear heuristic for pump operations. *J. Water Resour. Plan. Manag.* **1995**, *121*, 302–309. [CrossRef]

62. Bagirov, A.; Barton, A.; Mala-Jetmarova, H.; Al Nuaimat, A.; Ahmed, S.; Sultanova, N.; Yearwood, J. An algorithm for minimization of pumping costs inwater distribution systems using a novel approach to pump scheduling. *Math. Comput. Model.* **2013**, *57*, 873–886. [CrossRef]
63. Blinco, L.J.; Simpson, A.R.; Lambert, M.F.; Marchi, A. Comparison of pumping regimes for water distribution systems to minimize cost and greenhouse gases. *J. Water Resour. Plan. Manag.* **2016**, *142*, 04016010. [CrossRef]
64. Goldman, F.E.; Mays, L.W. The application of simulated annealing to the optimal operation of water systems. In Proceedings of the 29th Annual Water Resources Planning and Management Conference, Tempe, AZ, USA, 6–9 June 1999; pp. 1–16.
65. Wegley, C.; Eusuff, M.; Lansey, K. Determining pump operations using particle swarm optimization. In Proceedings of the Joint Conference on Water Resource Engineering and Water Resources Planning and Management, Minneapolis, MN, USA, 30 July–2 August 2000; pp. 1–6.
66. Raso, L.; Schwanenberg, D.; van de Giesen, N.C.; van Overloop, P.J. Short-term optimal operation of water systems using ensemble forecasts. *Adv. Water Resour.* **2014**, *71*, 200–208. [CrossRef]
67. Grycan, W. Congruent modelling as a tool for forecasting of households electricity consumption. In Proceedings of the 2016 Progress in Applied Electrical Engineering (PAEE), Koscielisko-Zakopane, Poland, 26 June–1 July 2016. [CrossRef]
68. Spees, K.; Lave, L. Impacts of responsive load in PJM: Load shifting and real time pricing. *Energy J.* **2008**, *29*, 101–122. [CrossRef]
69. Alvisi, S.; Franchini, M. A Methodology for Pumping Control Based on Time Variable Trigger Levels. *Procedia Eng.* **2016**, *162*, 365–372. [CrossRef]
70. Nęcka, K. Efficiency analysis of changing rate of group on example of sewage treatment plant. *Agric. Eng.* **2012**, *16*, 257–266.
71. Zhang, H.; Zhao, F.; Fang, K.; Sutherland, J.W. Energy-conscious flow shop scheduling under time-of-use electricity tariffs. *CIRP Ann. Manuf. Technol.* **2014**, *63*, 37–40. [CrossRef]