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Full Length Research Paper

Performance of pumped irrigation systems and evaluation of energy efficiency: A case study of the Bagarasi and Turkelli systems in Turkey

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The sustainability (*SAI* and *AIR*), cost (*MBR, PCR, ECR* and *CPA*) and energy consumption (*SEC* and *RAI*) performance of Bagarasi pumping irrigation system (BPIS) and Turkelli pumping irrigation system (TPIS) pumped irrigation systems were determined according to these 8 indicators. Also, the potential energy saving and repayment period on investment for replacing the standard electric motors with high efficiency motors was determined. Calculated values of *SIA* for BPIS (445.9%) and TPIS (36.7%) were below the ideal. Calculated actual values of *AIR* for BPIS (13.7 ha km^{-1}) and TPIS (15.4 ha km^{-1}) were lower than indicator values calculated according to the system's projected values. These indicators showed that the system was not sustainable with regard to irrigated area and infrastructure. *MBR* values for BPIS (7.3%) and TPIS (6.2%) were lower than the ideal. *ECR* value of BPIS (27.5%) was lower than that for TPIS (55.5%). The value of *PCR* for BPIS (61.3%) was higher than that for TPIS (34.3%). Calculated *CPA* values for both TPIS (178 \$ha^{-1}) and BPIS (513 \$ha^{-1}) were higher than the indicator values calculated according to the system's projected values. Cost indicators showed that in both systems maintenance work was inadequate, energy expenditure was higher than other forms of expenditure and that the unit price of irrigation water was high. SEC_a and SEC_i values were 0.051 kWhm^{-3} and 0.020 kWhm^{-3} respectively for BPIS and 0.105 kWhm^{-3} and 0.029 kWhm^{-3} for TPIS. *RAI* values for BPIS (39.80%) were higher than that for TPISs (27.53%). In addition, *RAI* values for the year after a compensation system was installed for BPIS did not exceed the projected limit. These indicators show that the use of energy in TPIS was relatively good compared to BPIS. The use of high efficiency motors secured a 10.87 - 13.89% energy saving in the systems. The repayment period for the motors was less than 2 years. To improve system performance, efficiency in the transmission and use of water must be improved and high efficiency motors must be used to power the pumps. Also, if energy monitoring and control systems are installed which operate remotely and in real time, these will increase the efficiency of energy use.

Key words: Performance, irrigation, water pumping, energy efficiency, Bagarasi, Turkelli.

INTRODUCTION

Electricity forms a large part of the expenditure in agricultural production and this is increasing significant with the spread of new technology. Electricity consumption in Turkey's agricultural sector increased by 55% between 1990 and 2003, and in 2003 consumption by agriculture formed 3.7% of total electricity consumption (Karkacier and Goktolga, 2009). One of the best ways of ensuring electricity supplies is to save energy. The preferred policy in Turkey to meet the need for electricity has been to establish new power stations, unlike countries of the EU which are increasing efficiency of

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Abbreviations: SAI, Sustainability of irrigated area; **AIR,** area/infrastructure ratio; **MBR,** maintenance budget ratio; **PCR,** personnel cost ratio; **ECR,** energy cost ratio; **CPA,** cost per unit area; **RAI,** ratio of active energy to inductive energy; **SEC,** specific energy consumption; **LF,** load factor.

energy use. Nevertheless, new laws since the year 2000 have provided support for work on energy efficiency and its monitoring and coordination (Keskin, 2007). Among the targets announced by the general directorate for electrical surveying (EIE) in its strategic plan for 2009 to 2013 is “the development and application of ways to use energy and energy resources more efficiently” (EIE, 2008). When surface water sources are used, pumps may be needed if the potential energy of the water is inadequate and in pumped irrigation, water is raised to the land at higher elevations by means of centrifugal pumps. Electrical energy used in pumped systems is generally in the form of alternating current. Alternating current is made up of an active force and a reactive force. The active force is the one which provides the mechanical turning power and turns the shaft of the motor. The reactive force on the other hand provides the magnetism in the stationary parts of the motor which causes the motor to turn.

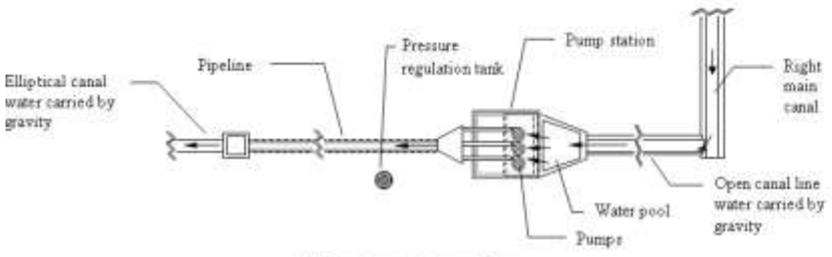
The electrical energy input to pumped irrigation constitutes an added expense to irrigation. The high operating losses in pumped irrigation networks and irrigation by low efficiency surface irrigation techniques cause excessive use of both electric power and water, thus increasing the cost of production (Erkin, 1997; Kilic, 2005). In another study, it was found that 20% of saving in electrical energy could be made by choosing suitable pumps, by taking appropriate technical measures, by applying good operation and maintenance practices (Erkin, 1997). In a study on a pumped irrigation system in Spain, it was found that simple electrical and hydraulic measurements could be carried out using network electrical analyzers in the pumping stations, flow meters and pressure exchanger, thus securing 16% saving in expenses and that the extra costs incurred could be met by the increase in energy efficiency in a single season (Moreno et al., 2007). In large irrigation systems especially, it has been found that computerized optimal real-time control of the pumping station can be enabled by coupling a commercial controller to a micro-computer. Thus, the use of a computer controller which is currently available in the market can save up to 10% on pump expenses (Sabbagh and Sinai, 1988).

The high performance pumps used in irrigation generally operate for 3000 hours or more per year. The pump is made up of the pump shaft, impeller, helix, shaft bearing, gasket, suction bend, suction pipe and output valve. Estimated service lifetimes are about 9 years for pump reconditioning, 3 years for pump readjustment, 16 years for the reduction gears, 15 years for high performance motors, 20 years for ground-mounted pumps and 15 years for pipe-mounted pumps (PG and E, 1997). Parts of the pump in contact with water show wear because of the silt and sand in the irrigation water. Karaca (2005) found that as the silt level in irrigation water increased, pump flow rate, pressure and output decreased and power consumption and shaft wear increased. Yuksel and Eker (2009) found that when centrifugal pumps were used for long periods the impellers, which were made of non-durable materials, could suffer damage. This kind of deformation in centrifugal pumps increases energy consumption. Efficient operation and management of an irrigation system plays an important role in the sustainability of irrigated agriculture (Mishra et al., 2001). For this reason, irrigation project performance studies are being used with increasing frequency to promote this objective. Today, for the reasons stated above, the evaluation of the performance of pumped irrigation systems with regard to energy consumption has gained great importance. In order to obtain efficiency in the use of energy and thus energy saving, the structure and management of existing pumped water irrigation systems must first be improved.

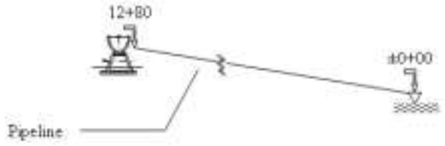
In general, 85% of the lifecycle costs of a pump are its energy expenses, 10% is service and maintenance, 5% is the purchase price (European Commission, 2003). Many users are still making their motor purchasing decisions based on the initial purchase cost, but it is vital to evaluate the differences in energy efficiency between motors offered by various manufacturers and to choose only those that clearly meet the criteria for efficiency. An investment of 30 – 50% more for a highly efficient motor can be recovered in a relatively short period of time. Furthermore, for some motors, the cost of the extra energy wasted by a standard motor exceeds the original motor price within the first year of operation. In fact, the average initial purchase cost of a motor only makes up 2 – 16% of the total cost of ownership, depending on the motor size (Turner and Doty, 2007).

Studies evaluating performance of the general gravity-fed open canal irrigation systems have been made in Turkey since the 1990s and the agricultural, environmental, economic and social performance indicators of various irrigation systems have been determined (Avci and Unal, 2008). In pumped irrigation systems where water in an open canal system is raised to a higher level by pumps, there are significant problems regarding energy consumption. In order to solve these problems, it is necessary to evaluate the performance of this kind of system in terms of efficiency of the use of energy. The Bagarasi and Turkelli pumped irrigation systems are located in the right bank irrigation system of the Menemen plain, part of the lower Gediz Basin, which is one of the most important basins of the Aegean region of Turkey.

The 1999 - 2003 performance of these two sys-tems was examined in terms of irrigation ratio, revenue collection ratio, adequacy, efficiency reliability and equity and both systems were found to be weak in terms of these performance indicators (Yerlikaya, 2007). With recent increases in the price of electricity, the efficiency of energy consumption of this kind of pumped system has become crucial. However, there are no studies on this topic. In this study, the Bagarasi and Turkelli pumped



a) Water transmission network



b) Water raising line

Figure 1. Schematic outline of BPIS.

irrigation systems were taken as an example for the evaluation of performance and efficiency of energy use, their sustainability, cost and energy use performance was monitored in the irrigation seasons of 2002 - 2008 and suggestions were made for the improvement of system performance and efficiency in energy use.

MATERIALS AND METHODS

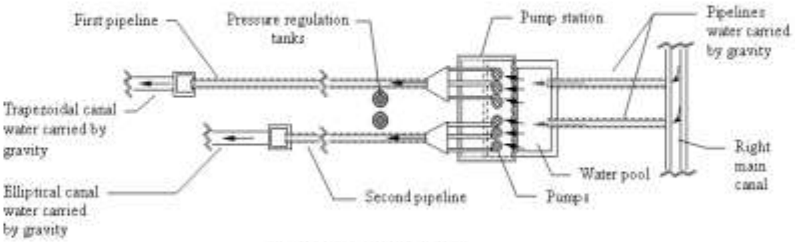
Materials

This research study was carried out in the Menemen plain, which is located in the Gediz Basin. The Gediz Basin is located within the Aegean region of Western Turkey, at latitude 38°04′-39°13′ N and longitude 26°42′-29°45′ E (Girgin et al., 1999). The study area has a continental climate. Rain falls mostly in the winter months, while summers are dry. The effect of the Aegean sea is felt in the inland because the mountains run perpendicular to the sea (TOPRAKSU, 1971).

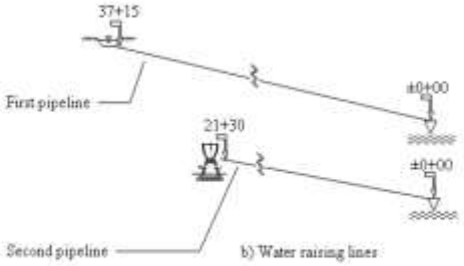
According to climatic data for the Menemen plain, for the period 1954 - 2008, the average annual air temperature was 16.9°C and the yearly total values of evaporation and rainfall were 1532.1 mm and 525.3 mm, respectively. Year-by-year rainfall totals for the years between 2005 and 2008 were 376.6, 366.0, 219.2 and 429.7 mm (TAGEM, 2006 and 2008).

The Menemen plain is irrigated by the left and right main canal irrigation networks constructed by the DSI. As with other networks, operation and maintenance of the right bank main canal network was handed over in 1995 from the DSI to the locally-controlled Menemen right bank irrigationassociation (MRBIA). The main source of water for the lower Gediz Basin irrigation system on the Menemen plain is the Demirköprü Dam on the Gediz river and Marmara Lake within the basin. In the months when plant water consumption is high (June - September) water for the irrigation systems in the basin is obtained from the dam and the lake and in other months it is taken from the river bed. Water is diverted to the irrigation systems by means of the Adala, Ahmetli and Emiralem regulators, constructed downstream of the dam and water for the left and right main canal irrigation systems serving the Menemen plain is diverted from the Emiralem regulator. Water charges are reassessed annually by the MRBIA according to crop type and land area and payments are collected from the farmers. The tradition is to plant crops with a high water requirement on the Menemen plain, principally cotton and also maize, summer vegetables and various kinds of fruits. Irrigation water is delivered by gravity in the left canal network, but in some parts of the right canal network, namely the Bagarasi pumping irrigation system (BPIS) and the Turkelli pumping irrigation system (TPIS), irrigation water is delivered by pumped systems. The schematic outline of the water transmission network and the water raising lines of BPIS and TPIS are given in (Figures 1 and 2). In both pumped irrigation areas, the cost of water to irrigate mainly cotton and maize by surface irrigation methods is up to twice that of gravity-fed areas. The most important factor in this difference is the cost of electrical energy used in pumping. Recent increases in the cost of electricity have made it difficult for the irrigation associations to meet their operating costs. This is because, as the price of electricity has risen, so has the cost of pumped irrigation water and so the demand for irrigation water in these areas has declined. In addition, the drought in this area in the past two years has caused a reduction in the available water for the pumped irrigation areas of the right main canal network. For these reasons, there has been a significant reduction in pumped irrigation areas. The associations' management state that they have difficulty in meeting the cost of energy with the revenue collected for the declining amount of water used. This has had a negative effect on spending on the running of the system, repair and maintenance expenditure especially has seen a significant reduction. This includes spending not only on pump maintenance but also on repairing the motors that drive the pumps. (Table 1) shows the foundation years, irrigated areas, irrigation canal length, number of pumps, year of manufacture of pumps, pump operating pressures and pump output values for BPIS and TPIS.

The pump output values (η_{pump}) on the labels of the centrifugal pumps of both systems, installed about 30 years ago, are 77% for BPIS and 80% for TPIS. The irrigated area and the length of open canals used to deliver pumped water to the irrigated areas of TPIS are about five times greater than those of BPIS. Three of the pumps in BPIS which are used to raise water from the main canal to the higher irrigated areas and six in TPIS, are over 30 years old (Table 1). (Table 2) gives pump capacities in the pumped irrigation static



a) Water transmission network



b) Water raising lines

Figure 2. Schematic outline of TPIS.

Table 1. Properties of the pumped irrigation systems.

Properties		BPIS	TPIS
Year of establishment		1978	1982
Area irrigated (ha)		290	1 475
Length of irrigation canal (m)	Trapezoidal canal	21 208	6 355
	Elliptical canal	-	95 895
	Total	21 208	102 250
Number of pumps		3	6
Year of manufacture		1976	1977
Yield (η_{pump}) (%)		77	80
Working pressure (kgcm^{-2})		6	6

Table 2. Properties of pumps in the pumped irrigation systems.

Pumped irrigation system		No. of pumps	Pump capacity (m^{3}s^{-1})	Static head (m)	Length of penstock (m)
BPIS		3	0.125	12.80	644
TBIS	1st Transmission Line	3	0.315	21.30	1 640
	2nd Transmission Line	3	0.350	37.15	926

head and length of penstocks and (Table 3) shows the number, power, total installed capacity, and power factor label values (PF_{label}) of the pump motors. BPIS have a single water delivery line, while TPIS has two separate lines. The capacity of each of the three pumps in BPIS is 0.125 m^{3}s^{-1} and static head is 12.80 m. The capacity of each of the pumps feeding TPIS no. 1 line is 0.315 m^{3}s^{-1} and static head is 21.30 m. The capacity of each of the three pumps feeding TPIS no. 2 line is 0.350 m^{3}s^{-1} and its static head is 37.15 m. The pumping capacity of TPIS (1.995 m^{3}s^{-1}) is almost six times that of BPIS (0.375 m^{3}s^{-1}) (Tables 2 and 3; Figures 1 and 2). 30kW uniform electric motors of a single type are used in the BPIS pumps. The motors used in the TPIS pumps have two different power values. The pumps on line no. 1 are driven by 110 kWh motors, those on line no. 2 by 200 kWh motors (Table 3).

Methods

In this study the performance of the pumped irrigation systems of Bagarasi and Turkelli was evaluated for sustainability, cost performance and energy use efficiency. In addition, an evaluation was made of energy saving by increasing the efficiency of energy use in the systems. The flow rate of the pumps (m^{3}h^{-1}) and their efficiency (%) were taken from their label values. Evaluation was

Table 3. Properties of electric motors of pumps in the pumped irrigation systems.

Properties	BPIS	TPIS		
		1st transmission line	2nd transmission line	Total
Number of motors	3	3	3	6
Power of motors (P_{label}) (kW)	30	200	110	330
Total installed power (kW)	90	600	330	930
Power Factor (PF_{label})	0.863	0.860	0.860	-

made according to a total of six indicators: sustainability of irrigated area (*SIA*) and area/infrastructure ratio (*AIR*) for system sustainability and maintenance budget ratio (*MBR*), personnel cost ratio (*PCR*), energy costratio (*ECR*) and cost per unit area (*CPA*) for finance (Nelson, 2002). Two other indicators, the ratio of active energy to inductive energy (*RAI*) and specific energy consumption (*SEC*), were used to evaluate system energy use performance.

Sustainability performance indicators

The indicator of sustainability of irrigated area (*SIA*) was calculated by means of equation 1.

$$SIA = \frac{A_C}{A_T} \quad (1)$$

Where A_c is current total irrigated area (ha) and A_T is total irrigated area when the system was first contstructed (ha). SIA≈100% shows that the system is sustainable, *SIA*<100% indicates a declining trend in irrigated area and that the system is not sustainable. This may be because of problems with water delivery, or for environmental or economic reasons. *SIA*>100% shows that water delivery has spread beyond the planned area, or that delivery capacity has been exceeded.

The indicator of area/infrastructure ratio (*AIR*) was calculated by means of the following equation.

$$AIR = \frac{Ac}{Lc} \quad (2)$$

Where *Ac* is current total irrigated area (ha) and L_C is the total length of canals and laterals on the system (km). The critical value of *AIR* (ha km^{-1}) depends on the economy of the region. Irrigated areas which easily meet infrastructure costs will have a higher indicator than that of other irrigated areas.

Financial performance indicators

The indicator maintenance budget ratio was calculated by means of the following equation.

[illegible] (3)

Where E_M is annual expenditures for maintenance ($) and E_T is total annual expenditures ($). The size of *MBR* (%) shows the importance given to maintenance in the water distribution system. The optimum value of the indicator varies according to region. In systems where maintenance work is inadequate, the value of *MBR* will be low (*MBR*<50%).

The indicator of energy cost ratio (*ECR*) was calculated by means of the following equation.

[illegible] (4)

Where E_E is annual expenditures for energy ($) and E_T is total annual expenditures ($). The indicator *ECR* (%) shows whether energy costs in systems which used pumping rather than gravity tended to be higher than other expenses. This indicator was used to monitor energy expenses arising from the use of electric pumps in the irrigation systems under study.

The indicator of personnel cost ratio (*PCR*) was calculated by means of the following equation.

[illegible] (5)

Where E_P is annual expenditures on personnel ($) and E_T is total annual expenditures ($). *PCR* (%) enables monitoring of whether personnel-related costs show a trend to be higher than other expenses. The ideal value of this indicator varies between 50 and 60%. The size of this indicator showswhether the number of personnel is more than necessary or whether not enough has been spent on maintenance.

The indicator of cost per unit area (*CPA*) was calculated by means of the following equation.

$$CPA = \frac{E_T}{A_C} \quad (6)$$

Where E_T is total annual expenditures ($) and A_C is current total irrigated area (ha). The *CPA* indicator ($ha^{-1}) is used to compare similar systems in a region. Expense components of the system are required to be stable in the comparison.

E_T, which appears in equations 3, 4, 5 and 6 was calculated in the following way.

$$E_T = E_M + E_E + E_P + E_O \quad (7)$$

Where E_M is the actual expense on repair and maintenance of pumps, E_E is the actual expense on electricity consumed by the pumps, E_P is the expense on temporary and permanent personnel engaged in operating and maintaining the pumping stations and E_O

is other operating expenses of the pumping stations, such as lighting. The values of the basic variables used in calculating the sustainability and cost performance indicators were obtained from MRBIA records. Monthly and yearly costs in Turkish currency were converted to USD using the average rate of exchange for the year.

Performance indicators of energy use

The use of pumps to take water from a source and supply it to a distribution network results in an extra expense in comparison with networks where water is delivered by gravity. Monitoring the energy consumption performance of such systems can be helpful in keeping control over energy consumption. In this way, excessive energy use can be identified, measures can be taken tosave energy and thus system operating costs can be reduced. Energy management performance for the selected systems was determined according to the indicators of specific energy consumption (*SEC*) and the ratio of active energy to Inductive energy (*RAI*).

SEC (kWhm^{-3}) was calculated by means of equation 8 (Ertoz, 2005; EIE, 2009).

[illegible] (8)

Where EC_T is total annual energy consumption (kWh) and PW_T is the annual volume of water pumped (m^3). The energy consumption performance indicator was calculated using the active energy consumption value EC_a from the SEC_a indicator calculation and the inductive energy consumption value EC_i from the SEC_i indicator calculation. The optimum values of these indicators depend on the characteristics of the pumps used.

The *RAI* indicator was found by calculating the percentage ratio of the consumption of inductive energy by the motors supplying the motive force to the pumps used in the irrigation system (EC_i) to active energy consumption (EC_a), as in equation 9.

[illegible] (9)

In legislation on dependability and quality of supply in electricity supply systems in Turkey, a limit of 33% has been set for *RAI* (Official Gazette, 2007). Exceeding this limit is a punishable offence. EC_a and EC_i values for BPIS and TPIS in 2002 -2008 were obtained from the gediz electricity distribution company (GEDAS), which distributes electricity in the Izmir area and their PW_T values were taken from MRBIA records.

Analysis of efficiency of energy use

Efficiency and energy consumption of the pumps powering the system's pumps were determined. A calculation was made of the energy saved by replacing the standard motors with high-efficiency motors in order to secure more efficient energy use (Kaya and Gungor, 2002; Lobodovsk, 2002) and of the repayment period of these motors.

In this regard, a preliminary survey was carried out in the 2008 irrigation season, the condition of the system's pumps and motors was examined in situ and information was obtained on the operation of the system in interviews with DSI and MRBIA officials. In addition, the power of the motors while working ($P_{measured}$) was measured using a Circutor AR5 type portable energy analyzer. Characteristics of this analyzer are given in (Table 4). The load factor (*LF*) is important in the calculation of the efficiency values of the motors. *LF* values of the low-efficiency motors in the system were calculated by means of equation 10.

$$LF = \frac{P_{measured}}{P_{nominal}} \qquad (10)$$

Where $P_{measured}$ is the measured power (kW) and $P_{nominal}$ is nominal power (kW), which is equal to the power specified on the label (P_{label}). The true efficiency of the low-efficiency motors in use in the systems (η_{ELEM}) was determined using the calculated *LF* value and the motor efficiency curves of low/medium/high efficiency motors given by the (EIE, 1998). In connection with this, the required power ($P_{required}$) (kW) of each motor in the systems was calculated by means of equation 11.

$$P_{required} = P_{measured} \cdot \eta_{ELEM} \qquad (11)$$

Full-load motor efficiency values for the selected high-efficiency motors suitable for the required mechanical power (η_{EMFL}) were found as mentioned above according to the efficiency curves of the high-efficiency motors (EIE, 1998). The power drawn from the network by the selected motors in relation to these values (P_{drawn}) (kW) was found by means of equation 12.

[illegible] (12)

Power saving (*PS*) (kW) provided by the difference between the actual power values of the motors in the system and the value of power drawn from the electricity network by the selected motors was calculated below equation 13.

$$PS = P_{measured} - P_{drawn} \qquad (13)$$

Financial energy saving (*FES*) (\$year^{-1}) provided by the use of the selected motors in the pumped irrigation systems was calculated from the values of power saving (*PS*) (kW), average annual working time (*AWH*) (hyear^{-1}) and electrical energy unit price (*EUP*) (\$ kW^{-1}h^{-1}) by means of equation 14.

[illegible] (14)

Where the average working time per year between 2002 and 2008 for the motors powering each pump in the pumped irrigation systems was taken into account in calculating *AWH*. The repayment periods for the high-efficiency motors selected was found by comparing the difference between the average market prices of the low-efficiency motors in use and the high-efficiency motors selected to the *FES* values.

RESULTS AND DISCUSSION

Basic variables used to determine system performance

Performance indicators for BPIS and TPIS, operated by the MRBIA, were calculated from basic variables relating to the 6-month periods (April - September) in the irrigation seasons of 2002 to 2008 when the systems

Table 4. Principal measurement properties of Circutor type AR5 portable energy analyzer.

Measurement properties	Phases 1	Phases 2	Phases 3	Accuracy
Voltage (V)	+	+	+	% 0.5±2 steps
Current (A)	+	+	+	% 0.5±2 steps
Active power (kW)	+	+	+	% 1.0±2 steps
Reactive power (kVAr)	+	+	+	
Power factor (*PF*)	+	+	+	
Active power meter (kWh)			+	
Apparent power meter (kVAh)			+	
Reactive inductive power meter (kVArhi)			+	
Reactive capacitive power meter (kVArhc)			+	
Frequency			+	
Working environment temperature (°C)			0 - 45	
Min. recording interval (s)			5	
Min. Measurement Interval Adjustment (s)			5	

Table 5. Variables used in the calculation of performance indicators for BPIS.

Year	System variables				Energy consumption variables		Cost variables				
	A_c (ha)	A_T (ha)	L_c (km)	PW_T (m^3)	Ec_a (kWh)	Ec_i (kWh)	E_M ($)	E_E ($)	E_P ($)	E_O ($)	E_T ($)
2002	170.0	290	21.208	2 005 650	91 048	80 925	908	8 431	9 913	33	19 285
2003	178.4	290	21.208	1 788 300	86 489	77 843	2 333	11 447	4 293	667	18 739
2004	231.0	290	21.208	1 882 350	102 218	6 144	6 647	8 047	6 997	0	21 691
2005	132.0	290	21.208	1 762 200	84 384	5 939	501	8 866	27 834	928	38 130
2006	153.9	290	21.208	1 807 650	97 734	0	429	9 368	25 300	5 894	40 991
2007	40.0	290	21.208	295 200	15 157	7 087	447	756	33 270	1 506	35 979
2008	26.5	290	21.208	114 300	6 325	2 524	0	1 275	46 053	1 001	48 328
Average	133.1	290	21.208	1 379 379	69 051	25 780	1 609	6 884	21 951	1 433	31 878

were being operated. Data relating to the system (A_C, A_T, L_c and PW_T), electric energy consumption (EC_a and EC_i) and finance (E_M, E_E, E_P, E_O and E_T) are given for BPIS in (Table 5) and for TPIS in (Table 6). For BPIS, since no structural changes had taken place in the years under study, the values of the variables of A_T (290 ha) and L_C (21.208 km) were stable. A_C values varied between 26.5 ha and 231.0 ha according to years, with an average of 133.1 ha. A_C values for all years were less than the values projected (A_T=290 ha), especially in the last two years, 2007 and 2008, when they fell below 100 ha. PW_T values were between 0.11.10^6 m^3 and 2.01.10^6 m^3, with an average of 1.38.10^6 m^3. This value generally varied along with the increase and decrease of the irrigated area and was very low in the last years. The variables EC_a and EC_i relating to energy consumption varied respectively according to years from 6 325 – 102 218 kWh and 0 – 80 925 kWh with averages of 69 051 and 25 780 kWh. The financial variable E_T, in connection with the other components (E_M, E_E, E_P and E_O), was between $18 739 and $48 328, with an average of $31 878. The highest average value of the other financial variables was E_P = $21 951 and was followed, in order, by E_E = $6 884, E_M = $1609 and E_O = $1 433. These results show that the largest share of the operating costs of the systems were personnel expenses, followed by electrical energy costs (Table 5).

In the Turkelli system, as in the other system, the values of the variables relating to the water delivery system, A_I (1 475 ha) and L_C (102.25 km), were stable. Values of A_C were between 170.0 and 848.4 ha according to year, with an average of 540.7 ha. Values of A_C for all years were much lower than the planned values (1 475 ha). At the end of the factors there is much higher price of water in the pumped systems compared with water delivered by gravity. Connected to this is the fact that farmers in the area served by the system, used underground water or preferred dry agriculture. Values of

Table 6. Variables used in the calculation of performance indicators for TPIS.

Year	System variables				Energy consumption variables		Cost variables				
	A_c (ha)	A_T (ha)	L_c (km)	PW_T (m^3)	Ec_a (kWh)	Ec_i (kWh)	E_M ($)	E_E ($)	E_P ($)	E_O ($)	E_T ($)
2002	623.0	1 475	102.25	5 005 728	511 268	159 779	1 309	34 836	14 870	46	51 061
2003	692.3	1 475	102.25	5 279 778	520 665	151 108	4 666	52 617	6 222	2 333	65 838
2004	848.4	1 475	102.25	5 848 156	671 920	200 664	11 195	63 936	10 495	6 647	92 274
2005	577.3	1 475	102.25	5 322 744	566 328	158 539	4 082	57 167	33 401	742	95 392
2006	553.7	1 475	102.25	5 852 826	525 301	136 348	3 595	54 707	30 365	10 532	99 198
2007	320.2	1 475	102.25	2 328 480	234 510	50 135	9 785	20 813	39 924	3 510	74 031
2008	170.0	1 475	102.25	1 029 924	125 939	34 341	450	18 337	46 053	630	65 470
Average	540.7	1 475	102.25	4 381 091	450 847	127 274	5 012	43 202	25 904	3 492	77 609

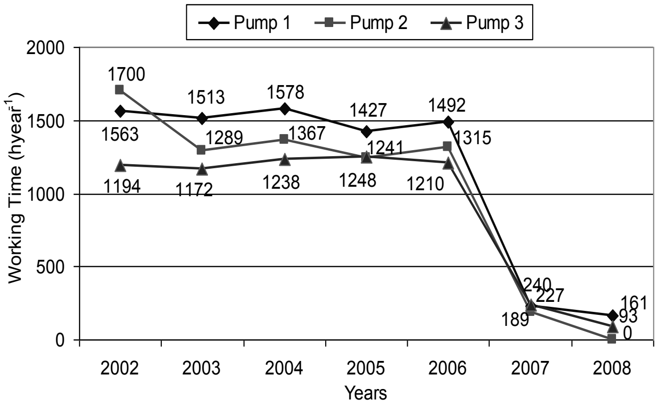


Figure 3. Total yearly working time of pumps in BPIS.

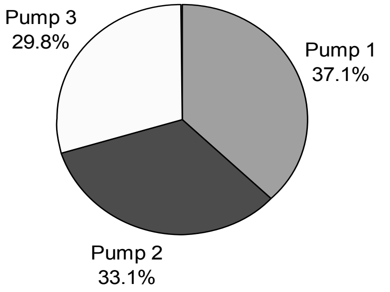


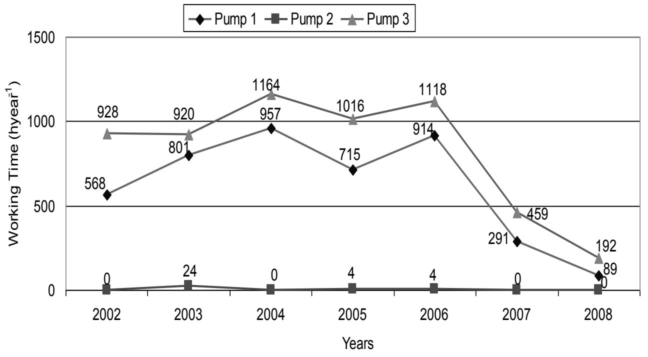
Figure 4. Average yearly working rations of pumps in BPIS.

PW_T were between $1.03.10^6$ m^3 and $5.85.10^6$ m^3, with an average of $4.38.10^6$ m^3. The values of the variables of energy use, EC_a and EC_i, varied between 125 939, 671 920, 34 341 and 200 664 kWh, respectively, according to years, with averages of 450 847 and 127 274 kWh. Parallel variations were seen in amounts of water pumped and electricity consumed in connection with the increase and decrease of irrigated area. Cost variable E_T was between $65 470 and $99 198, with an average of $77 609, in connection with the other four variables (E_M, E_E, E_P and E_O). Average values for the other cost variables were as follows: E_E = $43 202, E_P = $25 904, E_M = $5 012 and E_O = $3 492. These cost variables show that the greatest share of system operating expenditure went to electrical energy (Table 6).

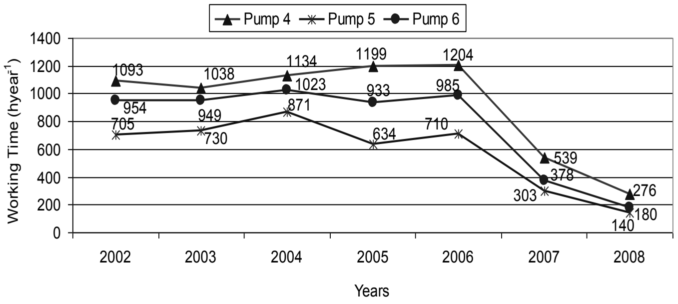
Periods and arrangement of working of pumps in the systems

The pumps of BPIS and TPIS are operated in different working arrangements and for different periods in the 6-month irrigation season from April to September. The year-by-year variation in the total working hours of each pump (hyear^{-1}) and the proportional value (%) of the average working period for all years are given in (Figures 3 and 4) for TPIS and (Figures 5 and 6) for BPIS. The pumps of BPIS, in order of proportional average operation periods, were pump no. 1 (37%; 161 -1 578 h year^{-1}), pump no. 2 (33%; 0-1700 h year^{-1}) and pump no. 3 (29.8%; 93-1248 h year^{-1}) (Figures 4 and 5). For the pumps serving line no. 1 in TPIS, the order was pump no. 3 (7.0%; 192-1164 h year^{1}), pump no. 1 (42.7%; 89-957 h year^{-1}) and pump no. 2 (0.3%; 0-24 h year^{-1}). For pumps serving the second line, the order was pump no. 4 (40.6%; 276-1204 h year^{-1}), pump no. 6 (33.8%; 180-1023 h year^{-1}) and pump no. 5 (25.6%; 140-871 h year^{-1}). It can be seen that the pump operation periods of the pumps in BPIS were more homogeneous than those of TPIS and that the working periods of pumps on line 1 of TPIS did not show internal homogeneity (Figures 5 and 6). Year-to-year variation in average monthly working periods according to the working arrangements of the pumps in BPIS and TPIS are given in (Figures 7 and 8).

The order of average monthly working periods of the various working arrangements of the pumps in BPIS was

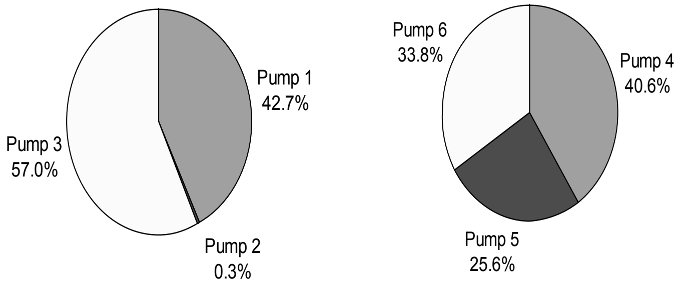


a) Pumps on first line.



b) Pumps on second line.

Figure 5. Total yearly working times of pumps in TPIS.



a) Pumps for first line. **b)** Pumps for second line.

Figure 6. Average yearly working ratios of pumps in TPIS.

as follows from most to least: all three together (111 h month^{-1}); pumps 1 and 2 together (34 h month^{-1}) and pump no. 1 by itself (25 h month^{-1}) (Table 7). The order for the pumps of TPIS line 1 was pumps 1 and 3 together (87 h month^{-1}) and pump 3 by itself (50 h month^{-1}). Pump 2 was kept in reserve and was not operated. The order for the pumps of line 2 was all three together (78 h month^{-1}), pumps 4 and 6 together (44 h month^{-1}) and pump 4 alone (26 h month^{-1}) (Table 8). In both systems, the working periods in the last two years of all pump operating arrangements were well below the averages of the last seven years. The data for the periods and arrangement of operation of the pumps of both systems show that no programme was followed in the operation of these pumps. MRBIA officials stated that pumps were operated in accordance with the amounts of water demanded and the state of repair of the pump motors. Moreover, if a pump could not be repaired, its pumps could be out of action for the whole season.

System performance

Values of indicators of sustainability (*SIA* and *AIR*), cost (*MBR, ECR, PCR* and *CPA*), and electrical energy consumption (SEC_a ve SEC_i) and calculated values for the years 2002 - 2008 are given in (Table 9) for BPIS and (Table 10) for TPIS. System performance is evaluated according to these indicators under the separate headings below.

Sustainability performance

The Bagarası system

SIA values were between 9.1 and 79.7% and averaged 45.9% (Table 9). These values were below the ideal value (<100%), but were relatively high compared to the *SIA* values of the other system. This shows that the water delivery of the system was not sustainable enough, but that it was in a better condition than the other system.

The value of *AIR* was between 1.3 -10.9 ha km^{-1}, with an average of 6.3 ha km^{-1} (Table 9). According to the projected value A_T= 290 ha, the ideal indicator value is *AIR* = 13.7 ha km^{-1}. This value is well above the calculated values for all years and especially the last two years. This shows that the sustainability of the system is not good with regard to infrastructure expenses, but that it is relatively good compared to the other system.

The Turkelli system

SIA values were 11.5 - 57.5%, with an average of 36.7% (Table 10). The fact that these values were well below the ideal value (<100%) shows that the system's lack sustainability stemmed mainly from economic factors. *AIR* values were 1.7-8.3 ha km^{-1}, with an average of 5.3 ha km^{-1} (Table 10). The projected value A_T = 1 475 ha gives the value of this indicator as *AIR* = 15.4 ha km^{-1}, which is far above the year-by-year calculated values. This demonstrates that the system is not sustainable with regard to infrastructure costs.

Cost performance

The Bagarasi system

MBR values were 0 - 30.6%, with an average of 7.3% (Table 9). In all years but especially in the last two years, this indicator value was well below 50%. This indicates

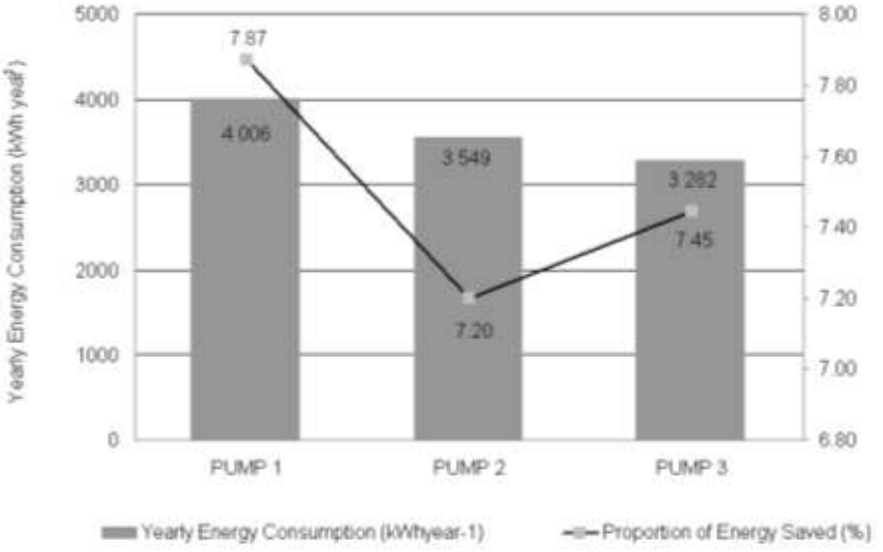


Figure 7. Yearly energy consumption and proportion of energy saved in BPIS.

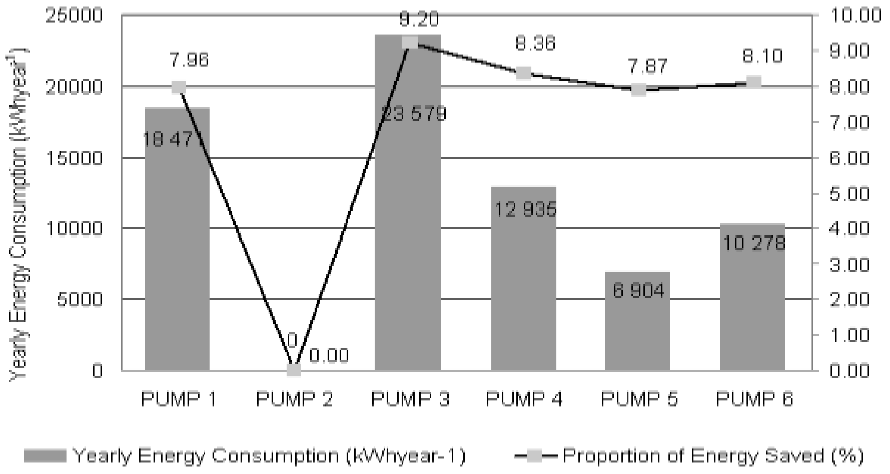


Figure 8. Yearly energy consumption and proportion of energy saved in TPIS.

Table 7. Average monthly working times in the irrigation season of pumps in BPIS according to the working arrangement.

Year	Working arrangements and times of pumps (h month^{-1})						
	Alone			Two together			Three together
	1	2	3	1+2	1+3	2+3	1+2+3
2002	12	7	10	75	12	16	156
2003	29	11	12	50	22	11	148
2004	42	5	4	33	10	20	173
2005	34	15	24	46	35	19	128
2006	32	14	10	30	17	6	165
2007	16	3	14	5	8	10	10
2008	11	0	0	0	16	0	0
Average	25	8	11	34	17	12	111

Table 8. Average monthly working times in the irrigation season of pumps in TPIS according to the working arrangement.

Year	Working arrangements and times of pumps (h month^{-1})													
	Pumps on 1st transmission line							Pumps on 2nd transmission line						
	Alone			Two together			Three together	Alone			Two together			Three together
	1	2	3	1+2	1+3	2+3	1+2+3	4	5	6	4+5	4+6	5+6	4+5+6
2002	6	0	55	0	96	0	0	24	4	3	6	48	3	104
2003	26	0	46	0	106	0	0	20	4	7	9	41	10	101
2004	27	0	59	0	127	0	0	32	2	13	17	80	2	94
2005	17	0	67	0	102	0	0	36	4	7	15	62	0	86
2006	27	0	77	0	115	0	0	31	2	13	20	55	2	95
2007	2	0	30	0	47	0	0	24	0	0	6	15	0	45
2008	0	0	17	0	15	0	0	16	0	0	0	7	0	23
Average	15	0	50	0	87	0	0	26	2	6	10	44	2	78

Table 9. Sustainability, cost and energy consumption performance indicators for BPIS.

Year	Sustainability		Cost				Energy consumption		
	SIA (%)	*AIR* (ha km^{-1})	*MBR* (%)	*ECR* (%)	*PCR* (%)	*CPA* (\$ ha^{-1})	*SEC$_a$* (kWh m^{-3})	*SEC$_i$* (kWh m^{-3})	*RAI* (%)
2002	58.6	8.0	4.7	43.7	51.4	113	0.045	0.040	88.88
2003	61.5	8.4	12.4	61.1	22.9	105	0.048	0.044	90.00
2004	79.7	10.9	30.6	37.1	32.3	94	0.054	0.003	6.01
2005	45.5	6.2	1.3	23.3	73.0	289	0.048	0.003	7.04
2006	53.1	7.3	1.0	22.9	61.7	266	0.054	0.000	0.00
2007	13.8	1.9	1.2	2.1	92.5	900	0.051	0.024	46.76
2008	9.1	1.3	0.0	2.6	95.3	1824	0.055	0.022	39.91
Average	45.9	6.3	7.3	27.5	61.3	513	0.051	0.020	39.80

Table 10. Sustainability, cost and energy consumption performance indicators for TPIS.

Year	Sustainability		Cost				Energy consumption		
	SIA (%)	*AIR* (ha km^{-1})	*MBR* (%)	*ECR* (%)	*PCR* (%)	*CPA* (\$ ha^{-1})	*SEC$_a$* (kWh m^{-3})	*SEC$_i$* (kWh m^{-3})	*RAI* (%)
2002	42.2	6.1	2.6	68.2	29.1	82	0.102	0.032	31.25
2003	46.9	6.8	7.1	79.9	9.5	95	0.099	0.029	29.02
2004	57.5	8.3	12.1	69.3	11.4	109	0.115	0.034	29.86
2005	39.1	5.6	4.3	59.9	35.0	165	0.106	0.030	27.99
2006	37.5	5.4	3.6	55.1	30.6	179	0.090	0.023	25.96
2007	21.7	3.1	13.2	28.1	53.9	231	0.101	0.022	21.38
2008	11.5	1.7	0.7	28.0	70.3	385	0.122	0.033	27.27
Average	36.7	5.3	6.2	55.5	34.3	178	0.105	0.029	27.53

that maintenance work was not being performed sufficiently on the system. However, more was spent on the maintenance of this system than for the other system under study. The value of the *ECR* indicator was 2.1 – 61.1%, with an average of 27.5% (Table 9). These values show that in the operation of the system, money spent on electrical energy was much more than that spent on maintenance. The value of the *PCR* indicator was 22.9 –

95.3%, with an average of 61.3% (Table 9). Apart from the first two years, the indicator values were above the ideal value (>60%) and the average value was above the average of the other indicators *MBR* and *ECR*. This shows that personnel costs were higher than other costs in the system. *CPA* values were \$94 ha^{-1} – \$1 824 ha^{-1}, with an average of \$513 ha^{-1} (Table 9). The average value of this indicator was higher than that of the other system. The projected irrigated area (A_T= 290 ha) and the average total annual costs (E_T=\$31 878) give a value of this indicator of *CPA*= \$71.7 ha^{-1}. This projected value is much lower than either the annual calculated values or the calculated average of annual values. This shows that cost per unit of irrigated area is very high. The basic reason for this is that the annually irrigated area in the system is much less than what was planned.

The Turkelli System

MBR indicator values were 0.7 - 13.2%, with an average of 6.2% (Table 10). These values were well below 50%, which shows that maintenance of the water delivery system was not carried out adequately.

ECR indicator values were 28.0 - 79.9%, with an average of 55.5% (Table 10). This value shows that money spent on electrical energy in the system was much higher than that spent on maintenance and personnel.

PCR indicator values were 9.5 - 70.3%, with an average of 34.3% (Table 10). The value of this indicator for all years except 2008 was below 60%. This shows that there was no great expenditure on personnel in the irrigation seasons of those years.

CPA indicator values were \$82 - \$385 ha^{-1}, with an average of \$178 ha^{-1} (Table 10). Projected irrigation area (A_T= 1 475 ha) and average total annual costs (E_T=\$77 609) give a value for this indicator of *CPA*= \$53 ha^{-1}. When these projected values are compared with the annual calculated values, it can be seen that costs per unit area were very high in the system for all years. The main reason for this is that the irrigated area in the system is less than what was planned. However, as with the other cost performance indicators, the value of the *CPA* indicator for the Turkelli system was much higher than that of the other system.

Energy use performance

The Bagarasi System

The energy consumption indicator values SEC_a and SEC_i were 0.045 - 0.055 kWhm^{-3}and 0 - 0.044 kWhm^{-3} respectively, with respective averages of 0.051 and 0.020 kWhm^{-3} (Table 9). The specific active energy consumption of the Bagarasi pumping station shows that while there was normal variation because of factors outside the energy system, the establishment of a compensator system in 2004 was able to bring it below the *RAI* limit value. However, the *RAI* values for 2007 and 2008 were above the projected limit values (Table 9). DSI and MRBIA officials stated that this situation stemmed from a breakdown in the compensator system and this kind of breakdown was generally caused by overheating of the compensator at high environmental temperatures and could sometimes not be repaired before the end of the season.

The Turkelli system

Energy consumption indicators SEC_a and SEC_i were 0.090 - 0.122 kWhm^{-3} and 0.022 - 0.034 kWhm^{-3} respectively, with respective averages of 0.105 kWhm^{-3} and 0.029 kWhm^{-3} (Table 10). Looking at the specific active energy consumption of the Turkelli pumping station, it can be seen that with the Bagarasi station, while there was normal variation because of factors outside the energy system, it paid a fine for exceeding the inductive limit value in some months and was only able to go below the *RAI* limit value when compensation equipment was set up in 2004.

Energy saving in the systems

The results of a preliminary survey on the structural andoperational condition of the motors powering the pumps of BPIS and TPIS are given in (Table 11). It was established that in neither system there was a kind of energy management system, nor had any study on energy efficiency been carried out. Thus, specific energy consumption and water pumping costs were not being monitored. Soft starters and speed control units were not used for energy efficiency. No time was set for maintenance other than when the motors broke down.

In 2004, the old compensation system in TPIS was renovated and a new compensation for BPIS and electricity metering systems for both systems were installed. (Table 12) shows the measurement values obtained by the portable energy analyzer for the pump motors of the two systems. It was found that the motors of BPIS were operated at 70.31% of load on average and that the motors of the first line of TPIS could be loaded at88.71% and those of the second line at 78.04%. Thus, the difference between the PF_{label} and $PF_{measured}$ values of the pump motors in the system shows that motors were not being run at full load (Table 12). (Table 13) shows the energy savings and the repayment periods when the low-efficiency motors in use in the BPIS and TPIS systems are replaced by high-efficiency motors. Average annual energy saving and energy saving ratios obtained by changing the motors are 10 836 kWh year^{-1} and 13.29%

Table 11. Pre-energy audit in pumped irrigation systems in 2008.

Checklist	BPIS	TPIS
Is there an energy management system?	No	No
Are there any studies to increase energy efficiency and decrease energy consumption?	No	No
Are energy consumption and product values examined?	No	No
In specific energy consumption (SEC) calculated?	No	No
Are these results evaluated later?	No	No
Are soft starters used in electric motors?	No	No
Are variable speed control units used in pumps and fans?	No	No
Is there any compensation?	Yes	Yes
Are electric motors serviced regularly?	No	No

Table 12. Label Values and Values Measured by Portable Energy Analyzer of the electric motors of the pumps in the BPIS and TPIS systems.

System		Pump no	Label value		Measured value		Loading ratio
			PF_{label}	P_{label} (kW)	$PF_{measured}$	$P_{measured}$ (kW)	($P_{measured}/P_{label}$) (%)
BPIS		1	0.863	30	0.76	22.01	73.37
		2	0.863	30	0.78	20.20	67.33
		3	0.863	30	0.74	21.07	70.23
		Average	0.863	30	0.76	21.09	70.31
TPIS	1st Line	1	0.860	200	0.85	160.79	80.40
		2	0.860	200	-	-	-
		3	0.860	200	0.88	194.03	97.02
		Average	0.860	200	0.87	177.41	88.71
	2nd Line	1	0.860	110	0.84	92.54	84.13
		2	0.860	110	0.82	80.49	73.17
		3	0.860	110	0.84	84.50	76.82
		Average	0.860	110	0.83	85.84	78.04

for BPIS, 42 050 kWh year^{-1} and 11.56% for the first line of TPIS and 30 116 kWh year^{-1} and 12.26% for the second line of TPIS. This energy saving provides an average financial saving of \$952 year^{-1} for BPIS, \$3 696 year^{-1} for the first line of TPIS and \$2 647 year^{-1} for the second line of TPIS. Also, the repayment period for these high-efficiency motors varies between 0.90 and 1.10 years for BPIS and 0.85 and 1.65 years for TPIS (Figures 8 and 9, Table 13). When the installations under study were compared based on data for the irrigation seasons of 2002 - 2008, it was determined that TPIS had a higher level of energy saving potential than BPIS.

The latest new technology is an early failure warning system, which enables the motors to be used at their highest efficiency. When the old electric motors are changed for new ones it will be possible to monitor their energy consumption on-line. Interviews with MRBIA personnel show that they attach no importance to energy management and efficiency because of a lack of information on this issue. It would be quite possible to determine this situation by examining the records which should be collected to meet the needs of energy management studies. The outline of energy management system is given in (Figure 9).

Conclusions

It was found in this study that sustainability and financial performance of both TPIS and BPIS were generally low, but that the financial performance of TPIS was relatively good compared with that of BPIS. In both systems, energy costs were very high in comparison with spending on maintenance and personnel. The personnel cost ratio of BPIS was higher than that of TPIS. The fact that spending on maintenance work in both systems was very low, it shows that adequate maintenance work was not being carried out in the water delivery systems. Also, it was seen that the cost per unit of irrigated area in both systems was very high. The main reason for this was that

Table 13. Energy saving from replacing low-efficiency electric motors with selected high-efficiency motors in the BPIS and TPIS systems and repayment periods.

System	Pump No	Energy consumption values				Payback time values				
		Consumption of low-efficiency motor (kWhyear^{-1})	Consumption of high-efficiency motor (kWhyear^{1})	Energy saving (kWhyear^{-1})	Energy Saving rate (%)	Price of high efficiency motor ($)	Price of low efficiency motor ($)	Price difference ($)	PET ($ year^{-1})	Payback time (years)
BPIS	1	31 525	27 519	4 006	12.71	1 462	1 144	318	352	0.90
	2	25 549	22 001	3 549	13.89	1 462	1 144	318	312	1.02
	3	24 437	21 155	3 282	13.43	1 462	1 144	318	288	1.10
	Total	81 512	70 675	10 836	13.29	4 387	3 432	955	952	1.00
TPIS	1	146 967	128 495	18 471	12.57	9 399	7 641	1 758	1 623	1.08
	2*	-	-	-	-	-	-	-	-	-
	3	216 926	193 347	23 579	10.87	9 399	7 641	1 758	2 072	0.85
	Total	363 892	321 842	42 050	11.56	18 798	15 282	3 516	3 696	0.95
	1	108 182	95 247	12 935	11.96	5 360	4 358	1 002	1 137	0.88
	2	54 330	47 427	6 904	12.71	5 360	4 358	1 002	607	1.65
	3	83 230	72 952	10 278	12.35	5 360	4 358	1 002	903	1.11
	Total	245 742	215 626	30 116	12.26	16 081	13 075	3 007	2 647	1.14

*Operated in case of breakdown of other pumps or motors.

area irrigated each year in the system was much less than the irrigated area originally planned for. More efficient use of energy and pumped irrigation water in the systems can increase the area of land irrigated and reduce the cost of energy used for irrigation. This can provide a significant contribution to improving system performance. This will necessitate new arrangements and practices both in the delivery of pumped water and its use on the land and in the use of electrical energy in pumping.

In both systems, the open canal system presently used for the distribution of water delivered by pumping should be replaced with a high transmission capacity piped system. Irrigation associations need to make a significant investment to carry out these changes. It was found that officials of both the DSI and the associations had as yet been unable to find the necessary source of financing for this investment. In addition to this, farmers should make use of high-capacity pressurized irrigation systems rather than surface irrigation methods when using water delivered to the network by pumping. Indeed, the government has recently been offering credit facilities to farmers to encourage the use of pressurized irrigation methods. The association must then organize information and education activities on the use of these methods, particularly in areas where pumped water is used for irrigation.

Current use of equipment and operational and monitoring practices in both systems has a detrimental effect on the efficiency of energy use. The current pumps and their motors have been in operation for around 30 years, so that they cannot be run at full load and their maintenance costs have increased. It was found however that their replacement with high-efficiency motors would create a significant potential for saving, as well as reducing energy expenditure. Also, the pump operation records of both systems are not useful for evaluating operation performance and energy efficiency. These records need to be kept in such a way that specific energy consumption and energy efficiency can be monitored. In addition, flow rates need to be measured at the pump outputs and records need to be kept in order to monitor pump efficiency. In order to operate the systems as described above, an effective energy management system must be applied. When an energy monitoring and control system is put into

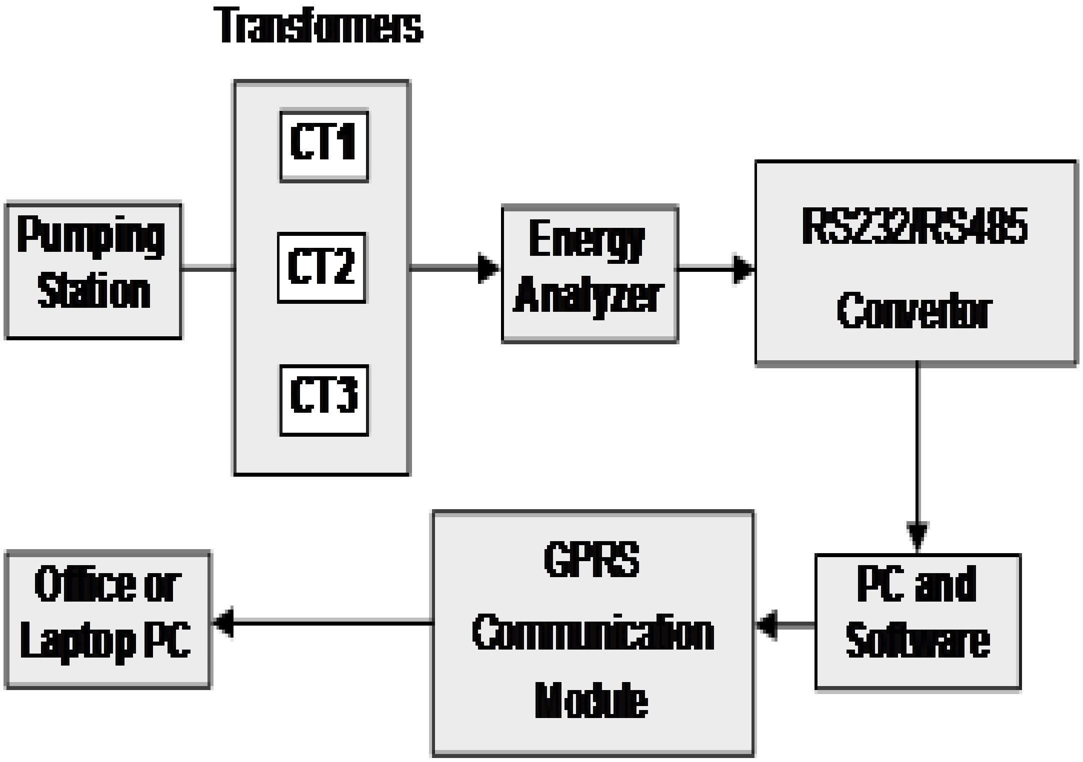


Figure 9. Main elements and flow chart of electrical energy monitoring and controlling system.

place, pump operation can be monitored and controlled remotely in real time by the irrigation association. In this way, the systems can be run more efficiently and productively. There is an urgent need for such energy management systems to be set up in all the irrigation associations of the Gediz Basin and help needs to be obtained from universities and expert organizations in order to achieve this objective.

REFERENCES

Avci M, Unal HB (2008). Performance of irrigation system in Turkey: A general review. 29th International Conference of CIGR Section IV: rational use of energy in agriculture and renewable energy sources in connection with environment protection, Szt. István University, Gödöllo-Hungary, Kutatasi Es Fejlesztesi Tanacskozas. Nr.32, 2.Kötet: pp. 55-60.

EIE (1998). Rules and announcements about energy efficiency. General Directorate for Electrical Surveying (EIE), National Energy Conservation Center (UETM), Ankara.

EIE (2008). Strategic plan for 2009-2013. General Directorate for Electrical Surveying (EIE), http://www.eie.gov.tr/2009-2013_eie_strateji.pdf, Ankara, Turkey.

EIE (2009). Energy efficiency in industry. Technical information series, General Directorate for Electrical Surveying (EIE), http://www.eie.gov.tr, Ankara, Turkey.

Erkin H (1997). The use of water pumps and energy saving in Trakya Region. 2nd Industrialization and Environment Symposium. Edirne, Turkey. pp. 351-362.

Ertoz AO (2005). Pumps and energy efficiency of pumping systems. VII. National Installations Engineering Congress /TESKON . Izmir, Turkey. pp. 3-11.

European Commission (2003). Study on improving the energy efficiency of pumps. European Commission. http://re.jrc.ec.europa.eu/energyefficiency/motorchallenge/ pdf/SAVEPUMPSFinalRe port_June_2003.pdf, UK.

Girgin A, Gecgel G, Gul S (1999). Performance of Gediz Basin irrigations in terms of water management. Izmir Water Congress. Izmir, Turkey. pp. 317-334.

Karaca M (2005). Effects of different silt mixture ratios on characteristics of centrifugal pumps and wheel materials. MSc. Thesis, Selcuk University, Graduate School of Natural and Applied Sciences, Konya, Turkey. p. 32.

Karkacier O, Goktolga ZG (2009). Energy use and efficiency in agricultre. <http://www.mskongre.org/ doc/ osmankarkacier.doc> .

Kaya D, Gungor C (2002). Energy saving potential in industry -I. Eng. Machine, 514: 20-30.

Keskin T (2007). Energy efficiency law and implementation process. Eng. Machine, 48(569): 106-112.

Kilic H (2005). Agricultural irrigation and energy. South East Anatolia Region energy forum Diyarbakir, Turkey, pp. 112-118.

Lobodovsk KK (2002). Electric energy management. Chapter 11. Energy Management Handbook, 4th Ed. USA.

Mishra A, Anand A, Singh R, Raghuwanshi NS (2001). Hydraulic modeling of Kangsabati main canal for performance assessment. J. Irrigation Drainage Eng.,127(1): 27-34.

Moreno MA, Carrión PA, Planells P, Ortega JF, Tarjuelo JM (2007). Measurement and improvement of the energy efficiency at pumping stations. Biosyst. Eng., 98(4): 479-486.

Nelson D (2002). Irrigation organization types and trends in the United States. Paper presented at the Sixth Symposium of the International

Network on Participatory Irrigation Management. Beijing, PR China pp. 21-27.

Official Gazette (2007). Directive on changes to be made in the directive related to safety and quality of supply on electricity transmission system. Official Gazette of Republic of Turkey, Ankara, Turkey. p. 26398.

PG and E (1997). Agricultural pumping efficiency improvements. Pacific Gas and Electric Company (PG&E), Application Note, p. 11.

Sabbagh E, Sinai G (1988). A model for optimal real-time computer control of pumping stations in irrigation systems. Comp. Elect. in Agric., 3(2): 119-133.

TAGEM (2006). Hydrometeorological observed data for 2004-2006 water years of Menemen. Ministry of Agriculture and Rural, General Directorate of Agricultural Research (TAGEM), Soil and Water Resources Research Institute, Menemen, Turkey.

TAGEM (2008). Hydrometeorological observed data for 2007-2008 water years of Menemen. Ministry of Agriculture and Rural, General Directorate of Agricultural Research (TAGEM), Soil and Water Resources Research Institute, Menemen, Turkey.

TOPRAKSU (1971). Basic soil survey of Menemen Plain. General Directorate of Soil-Water, Soil Survey and Mapping Office, Ankara, 236: 125.

Turner WC, Doty S (2007). Energy Management Handbook. 6th Ed. The Fairmont Press, Inc., Lilburn, GA, USA.

Yerlikaya S (2007). Evaluation of irrigation performance in Turkelli and Bagarasi pumping systems in the Menemen plain. MSc. Thesis, Ege University, Graduate School of Natural and Applied Sciences, Izmir p. 67.

Yuksel E, Eker B (2009). Determination of possible wear on the centrifugal pump wheel used for agricultural irrigation purposes. J. Tekirdag Agric. Faculty, 6(2): 203-214.