# Study on Improving the Efficiency of Irrigation Systems by Using Electricity Produced by Photovoltaic Panels

**Laura-Alexandra DOROFTEI***
*National University of Science and Technology POLITEHNICA of Bucharest, Romania*
* *lauradoroftei10@gmail.com*

**Gheorghe MILITARU**
*National University of Science and Technology POLITEHNICA of Bucharest, Romania*
*gheorghe.militaru@upb.ro*

**Ioan BITIR-ISTRATE**
*National University of Science and Technology POLITEHNICA of Bucharest, Romania*
*ioanistrate2005@yahoo.com*

**Abstract.** *In recent decades, climate change has put pressure on farmers to invest in efficient irrigation systems to keep their crops competitive. Given the importance of agriculture in securing food resources in the years to come, the reduction of water sources and the benefits of using renewable energy sources, the topic of irrigation using efficient photovoltaic panel-powered systems has been often discussed in the literature, especially in countries with a warm climate. Romania has a temperate-continental climate, beneficial for growing cereals, such as maize, but in recent years, especially in areas with low rainfall, the integration of irrigation systems has become strictly necessary. Thus, this research aims to contribute to the literature by providing an analysis of possible solutions for the development of such an efficient drip irrigation system powered by photovoltaic panels for an agricultural field in Romania. The use of such a system ensures crop yields are economically efficient and contributes to reducing emissions by replacing the use of fossil fuels. The information provided in this article is of interest to farmers, landowners or farmers' associations interested in developing such a system. The article provides information on components, possible sizing options, approximate costs and benefits, and aims to highlight the advantages of these systems.*

**Keywords**: irrigation systems, photovoltaic panels, drip irrigation system, efficiency, maize crops, economic efficiency.

## Introduction

In recent decades, climate change has put food security for the future in doubt. Rising temperatures coupled with prolonged periods of drought, particularly in the summer months, are having negative effects on crops. In Romania, due to pedo-climatic conditions, maize cultivation has been one of the main agricultural activities, but in recent years harvests have declined because of climate change.

One solution to ensure the water needs for growing cereals such as maize is the use of irrigation systems. In Romania, due to socio-economic conditions, irrigation was carried out in certain areas and the systems used had low efficiency, so nowadays farmers are faced with no irrigation systems at all or non-functional ones (Micu et al., 2017). Currently, irrigation systems are powered by fossil fuel engines that have high emissions of $CO_2$ and other harmful substances. During dry periods, air currents are lower so much of the pollution generated remains locally, depositing on soil and plants. Moreover, rising prices for conventional fuels have in recent years

DOI: 10.2478/picbe-2025-0237

begun to reduce farmers' incomes. Many farmers have preferred to irrigate for minimum plant water requirements rather than maximum yields because the cost of purchasing the fuel was not covered by the additional production achieved.

In general, the need for irrigation is found in areas with the highest solar radiation, which is the main cause of soil and plant water evaporation. At the same time, another effect of climate change, particularly in these areas, is the reduction of water resources. As water resources become increasingly scarce, it is becoming necessary to use drip irrigation where possible. This provides the optimal amount of water needed by the plant without wasting it. A suitable and efficient solution is to replace fossil fuel systems and use the high solar potential to power the pumps used for drip irrigation. Thus, the main purpose of this article is to highlight the economic and environmental benefits of investing in a drip irrigation system powered by energy produced by photovoltaic panels.



The article is organized as follows. The next section presents a survey of the need for irrigation systems, water requirements for maize crops and other such systems analysed. Next, the article highlights the research methodology based on an analysis of solutions for the implementation of the irrigation system. This was followed by the economic analysis of the two solutions, the current one using conventional fuels and the proposed one using energy produced from photovoltaic panels. It also highlights the expected economic and environmental benefits of adopting a panel system. Finally, the article presents the main conclusions from this research.

## Literature review

The last decades have been marked by increasing mean monsoonal temperatures, with Europe experiencing a warm-season (June-August) temperature increase of more than 1 °C and extreme droughts over the last three decades (Călugăr et al., 2024; Micu et al., 2017).

Maize is the most widespread crop in Romania, both because of its importance for human and animal consumption, but also because of the favourable growing conditions (climate, soil). In 2019, Romania accounted for 30% of the total area cultivated with maize in the European Community. The optimal temperatures for maize development are between 16 and 20 °C in May, 19 and 21 °C in June, 20 and 23 °C in July, 19 and 20 °C in August and 14 and 17 °C in September, with maize cultivation generally taking place from the second decade of April until the end of September (Vâtcă et al., 2021). The July-August monthly interval is the period with the highest seasonal heat stress load. The record duration of a heatwave was recorded in Giurgiu, between July 19 and August 10, 2012, with temperatures between 32 and 43 °C (Micu et al., 2017).

Since 2017 to date, summer temperatures have exceeded the multi-year average (by 2.7°C in June). Uneven rainfall distribution and high temperatures have negatively affected maize crops. In 2019, drought in the summer months affected the crops (Călugăr et al., 2024). Climate data for the period 2021-2023 indicate an increase in air temperature and solar radiation (sunshine duration reached 10-12 hours/day) and a deficient precipitation regime, concentrated in April-June (Mincu & Neculau, 2024). In addition to being a drought year, 2022 was also characterized by temperatures above 35°C in all three summer months resulting in the lowest maize crop yield. In 2023, increased temperature values from July associated with a lack of rainfall until near the end of the month negatively affected the crop (Călugăr et al., 2024; Nițu et al., 2024).

In the period 2007-2011, irrigation of maize crops was carried out only in the dry areas located in the south of the country, with an amount of 300 - 400 $m^3$/ha (Dobocan et al., 2013). Irrigation of the soil with a volume between 200-400 $m^3$/ha to ensure the active moisture index at 50% at depths of 0-40 cm and 0-80 cm has significant effects in increasing crop yield (Nițu et al., 2024). The average daily water consumption for maize crops varies between 17-57 $m^3$/ha, reaching 62 $m^3$/ha in July (Drienovski et al., 2016). To maintain maize crop yield, a plant consumes daily 15-25 $m^3$/ha in May, 35-45 $m^3$/ha in June and August, 50-60 $m^3$/ha in July. Crop yield can be reduced by about 30-70% in case of lack of water before tassel emergence and by up to 45% in case of low water supply for four consecutive days in the interval between tassel emergence and kernel development (Vâtcă et al., 2021).



The negative effects of prolonged droughts can be significantly reduced through the use of irrigation systems. Irrigation helps to compensate for the water deficit by providing the necessary moisture for healthy plant development (Siphiwe et al., 2024). Especially during the period of maximum plant consumption, irrigation systems play a decisive role in maintaining and increasing crop yields. Drip irrigation is considered a very effective method because it ensures optimal moisture at the plant root for long periods and reduces soil salinity (Nițu et al., 2024). Drip irrigation, also called micro irrigation or localized irrigation, releases a controlled volume of water and nutrients at the plant root, helping to save water and fertilizer. It is composed of a network of valves, pipes and narrow tubes that deliver water directly to the base of the plant (Gulve et al., 2018). The use of drip irrigation leads to a reduction in water consumption by 20 to 76% leading to increased crop productivity with reduced water consumption (Grant et al., 2024).

High-efficiency irrigation systems using photovoltaic panels are the main solution for areas that are not connected to utility grids. They help maintain or improve production and minimize the effect of drought, bringing economic, environmental and social benefits. The benefits will motivate farmers to produce crops, contributing to poverty alleviation in rural areas (Raza et al., 2021; Raghad et al., 2019). The sizing of the system requires studying several variations in the required energy depending on the two pumps used. A submersible pump pumps water into a reservoir, from which water is taken for drip irrigation. The introduction of an energy storage device (battery) improves performance and reduces the volume of the water reservoir (Stoyanov et al., 2021).

## Methodology

The research presented in this paper aimed to replace a conventional irrigation system with a more efficient one by utilizing the high photovoltaic potential in the area where the farmland is located. The research was carried out in several stages. First, the case study was presented. Next, a possible solution for the realization of an irrigation system using energy produced by photovoltaic panels was analysed. Finally, the two solutions were compared, highlighting the most economically efficient solution.

### *Case study*

The research presented in this article uses as a case study an agricultural land with a total area of about 10 hectares (105,000 $m^2$), located in Buturugeni, Giurgiu County (Figure 1). The land is used for maize production and is irrigated with a drip irrigation system consisting of two conventional fuel powered pumps, a water tank and a fuel tank. The first pump takes water from the source and stores it in the tank, while the second pump is used to feed the field irrigation piping system with water from the tank.


**Figure 1. Location of the irrigated field chosen as case study**

Source: Realized by the author using Google maps online application (https://maps.google.com/).

***Sizing of the drip irrigation system powered by energy produced using photovoltaic panels***

Sizing the system involves two successive steps:

*Water supply to the irrigation system* - will be provided by two pumps and a reservoir, modelled after the current field irrigation system. The two pumps will have the same capacity as the fossil fuel pumps but will use electricity.

*Ensuring energy needs* - to supply the two pumps required for irrigating during the day and after sunset. The system consists of photovoltaic panels and a storage system (batteries). The Photovoltaic Geographical Information System application made available by the European Commission was used to dimension the system.

An example of a drip irrigation system powered by energy produced from photovoltaic panels supported by an energy storage system is illustrated in Figure 2.

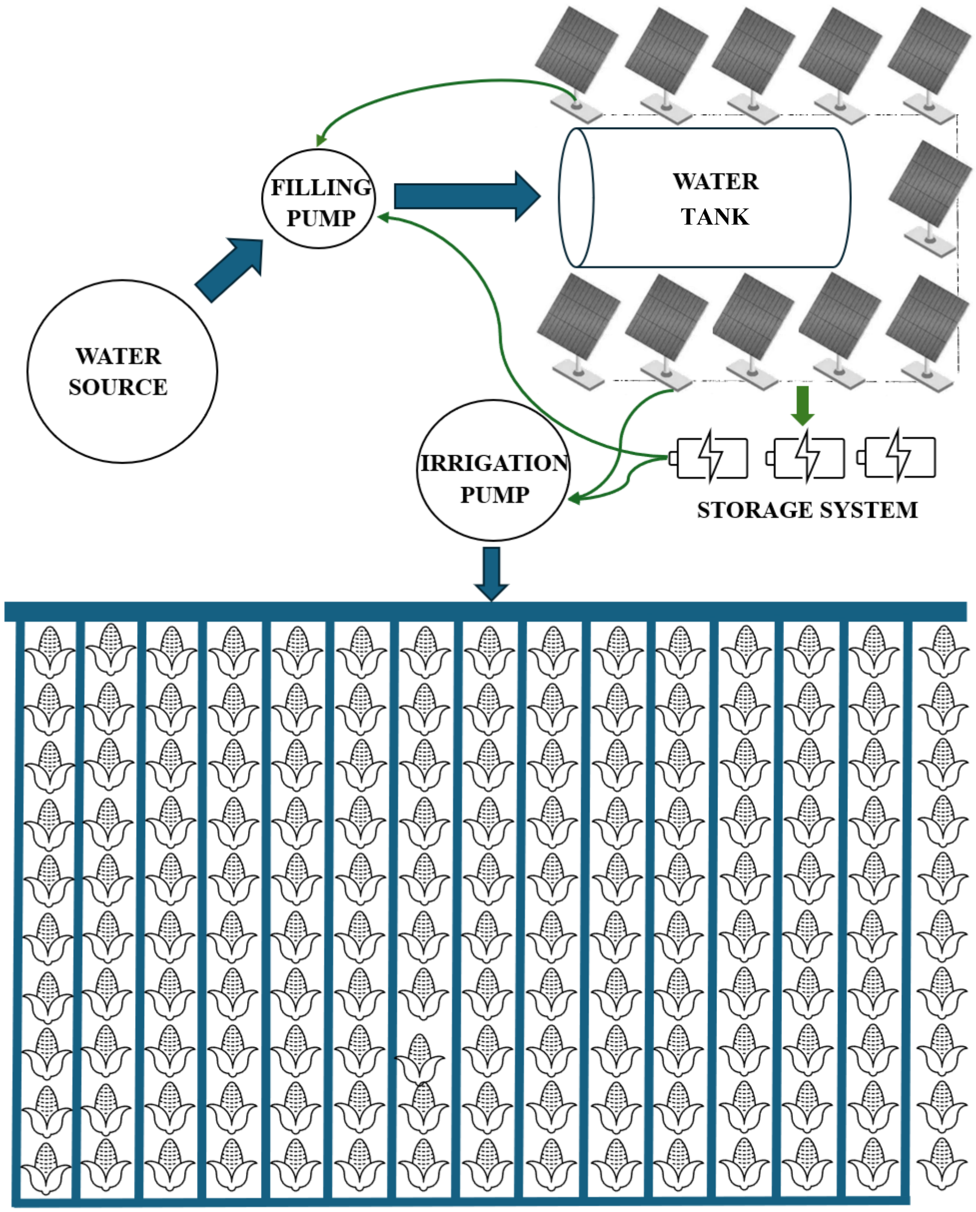


**Figure 2. Layout of a drip irrigation system powered by photovoltaic panels and batteries**

Source: Adapted after Raza et al., 2021; Raghad et al., 2019; Stoyanov et al., 2021.

***Proposed solutions for the irrigation system***

This section presents the two solutions for implementing the irrigation system. From these, following detailed analysis, the solution with the highest economic efficiency will be chosen.

Figure 3 shows the optimal amount of water needed to irrigate the maize crop. As the literature survey carried out earlier has shown a continuous increase in temperatures in recent years, especially in the analysed period (April-September), the use of the upper limits of the optimal irrigation water quantities was preferred for the calculations.

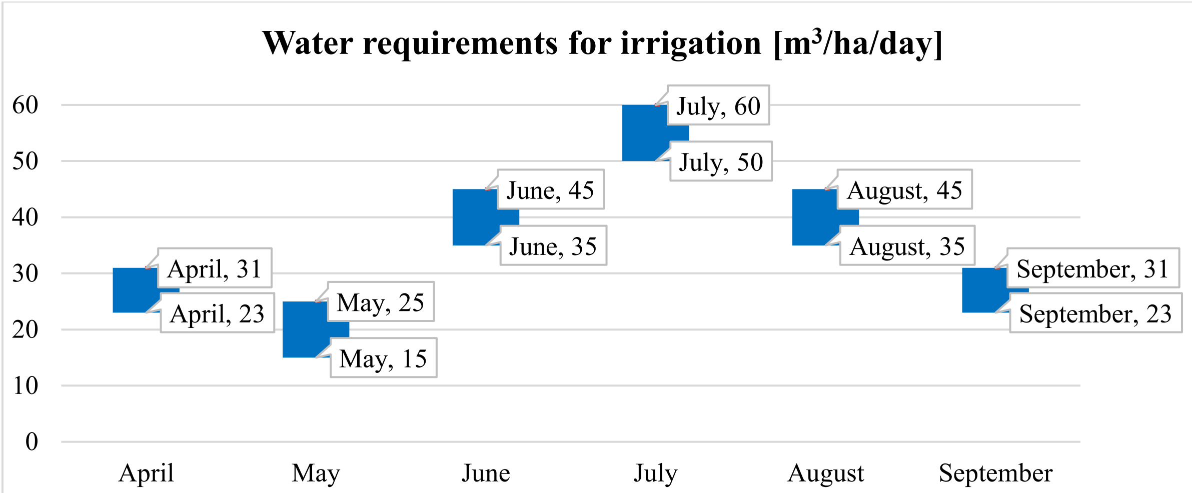


**Figure 3. Water requirements for irrigating the maize each month**
Source: Adapted after Niţu et al., 2024; Drienovski et al., 2016; Vâtcă et al., 2021.

In the following, a comparative analysis will be carried out to determine the economic efficiency of the photovoltaic panel irrigation solution. In both solutions, the land is irrigated with the same monthly water quantities with the help of two pumps, the main difference being the power source of the pumps.

***Existing solution***

In the existing solution, a gasoline powered pump with a maximum flow rate of 48 $m^3$/h is used to pump water from the source to the tank, with an average fuel consumption of 1.75 l/h. According to the data in Table 1, the annual gasoline consumption will be approximately 2,527 litres. This pump will fill a 50 $m^3$ tank.

**Table 1. Fuel consumption of the pump filling the water tank**

| ***Month*** | ***Total water required*** | ***Operating*** | ***Fuel consumption*** | |
|---|---|---|---|---|
| | ***[m³/day]*** | ***[h/day]*** | ***[l/day]*** | ***[l/month]*** |
| April | 310 | 6.46 | 11.30 | 226.04 |
| May | 250 | 5.21 | 9.11 | 282.55 |
| June | 450 | 9.38 | 16.41 | 492.19 |
| July | 600 | 12.5 | 21.88 | 678.13 |
| August | 450 | 9.38 | 16.41 | 508.59 |
| September | 310 | 6.46 | 11.30 | 339.06 |
| ***Total per year [l]*** | | | | ***2,526.56*** |

Source: Authors' own research.

For pumping water from the reservoir into the pipes of the irrigation system, a gasoline powered pump with a maximum flow rate of 40 $m^3$/h will be used with an average fuel consumption of 0.882 l/h. The data in Table 2 shows an annual consumption of 1,528 litres. Thus, the total gasoline consumption is approximately 4,055 litres/year.

**Table 2. Fuel consumption of the field drip system feed pump**

| ***Month*** | ***Total water required*** | ***Operating*** | ***Fuel consumption*** | |
|---|---|---|---|---|
| | ***[m³/day]*** | ***[h/day]*** | ***[l/day]*** | ***[l/month]*** |
| April | 310 | 7.75 | 6.84 | 136.71 |
| May | 250 | 6.25 | 5.51 | 170.89 |
| June | 450 | 11.25 | 9.92 | 297.68 |
| July | 600 | 15 | 13.23 | 410.13 |
| August | 450 | 11.25 | 9.92 | 307.6 |
| September | 310 | 7.75 | 6.84 | 205.07 |
| ***Total per year [l]*** | | | | ***1,528.07*** |

Source: Authors' own research.

***Proposed solution based on energy supply from photovoltaic panels sustained by a storage system (batteries)***

This solution will use the same water tank of 50 m$^3$ with a diameter of 3 m and a length of 7.58 m. A horizontal centrifugal pump (filling pump) with a flow rate between 9 and 48 m$^3$/h and an electrical consumption of 4 kW/h will be used to supply the reservoir with water. Total annual consumption is approximately 5,775 kWh/year. All the detailed data by months of operation is summarized in Table 3.

**Table 3. Energy consumption of the pump filling the water tank (Filling pump)**

| ***Month*** | ***Total water required*** | ***Operating*** | ***Energy consumption*** | |
|---|---|---|---|---|
| | ***[m³/day]*** | ***[h/day]*** | ***[kWh/day]*** | ***[kWh/month]*** |
| April | 310 | 6.46 | 25.83 | 516.67 |
| May | 250 | 5.21 | 20.83 | 645.83 |
| June | 450 | 9.38 | 37.5 | 1,125 |
| July | 600 | 12.5 | 50 | 1,550 |
| August | 450 | 9.38 | 37.5 | 1,162.5 |
| September | 310 | 6.46 | 25.83 | 775 |
| ***Total per year [kWh]*** | | | | ***5,775*** |

Source: Authors' own research.

The pump for supplying water from the tank (irrigation pump) to the irrigation pipes of the system is a horizontal centrifugal pump with a flow rate of 42 m$^3$/h and an electrical consumption of 3 kW/h. The detailed data of the irrigation pump per months of operation has been summarized in Table 4. Thus, the total energy consumption is approximately 10,972.5 kWh/year.

**Table 4. Energy consumption of the field drip system feed pump (Irrigation pump)**

| ***Month*** | ***Total water required*** | ***Operating*** | ***Energy consumption*** | |
|---|---|---|---|---|
| | ***[m³/h]*** | ***[h/day]*** | ***[kWh/day]*** | ***[kWh/month]*** |
| April | 310 | 7.75 | 23.25 | 465 |
| May | 250 | 6.25 | 18.75 | 581.25 |
| June | 450 | 11.25 | 33.75 | 1,012.5 |
| July | 600 | 15 | 45 | 1395 |
| August | 450 | 11.25 | 33.75 | 1,046.25 |
| September | 310 | 7.75 | 23.25 | 697.5 |
| ***Total per year [kWh]*** | | | | ***5,197.50*** |

Source: Authors' own research.

*Sizing the photovoltaic system for powering the pumps*

To meet the energy needs, an installed capacity of 20 kW was approximated using the platform provided by the European Commission. If photovoltaic panels of 450 W, measuring 1.722 x 1.134 m, are installed, it will be necessary to purchase 45 panels. In order to save space, it is proposed to install the panels horizontally, in three rows, two with double support systems of nine panels each and one row consisting of a single system of nine panels, placed over the area where the buried tank is mounted and occupying a total area of approximately 218 $m^2$. A 25-kW inverter will also be purchased.



As can be seen in Figure 5, by superimposing the annual consumption curve and the monthly production curve of the PV system approximated by the platform, the entire energy requirement is covered.

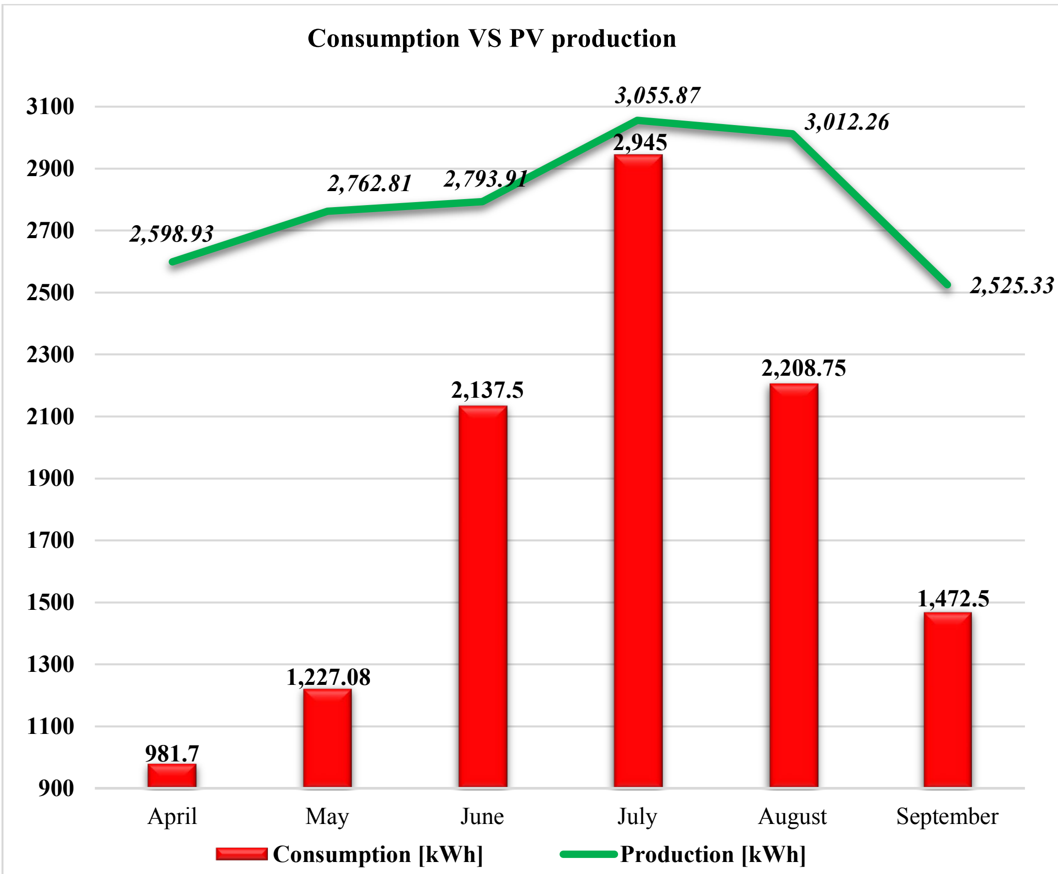


**Figure 5. Providing energy for pumps with photovoltaic panels**

Source: Realized by the author using Photovoltaic Geographical Information System (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#).

The sizing of the battery storage system will consider the coverage of the energy needs for the operation of the pumps after sunset. To cover the energy needs in the month with the highest consumption, it is necessary to purchase a battery of approximately 19 kW, as shown in Table 5. To cover possible losses in the system and for reasons of resilience, a 25-kW system will be purchased.

**Table 5. Sizing the storage system (batteries) to provide the necessary irrigation during periods without sunshine**

| *Month* | *Total solar irradiation* | *Filling pump* | *Uncovered hours* | *Irrigation pump* | *Uncovered hours* | *Battery power consumption* |
|---|---|---|---|---|---|---|
| | *[h/day]* | *[h/day]* | *[h/day]* | *[h/day]* | *[h/day]* | *[kW/day]* |
| April | 10 | 6.46 | 0 | 7.75 | 0 | 0 |
| May | 10.5 | 5.21 | 0 | 6.25 | 0 | 0 |
| June | 11.5 | 9.38 | 0 | 11.25 | 0 | 0 |
| July | 11.5 | 12.50 | 2 | 15 | 3.5 | 18.5 |
| August | 11 | 9.38 | 0 | 11.25 | 0.25 | 1.05 |
| September | 10 | 6.46 | 0 | 7.75 | 0 | 0 |

Source: Authors' own research.



***Analysis of the economic viability and benefits of the proposed solution***

At this stage, the calculation of the investment required to purchase all the equipment necessary to realize the two solutions was made. A cash flow analysis was also performed, and economic and environmental benefits were highlighted.

## Results and discussions

After presenting the two solutions, the existing and the proposed one, a comparative analysis follows to justify the investment in the use of photovoltaic panels. The analysis aims to determine whether the proposed solution is more economically efficient than the existing one.

The option will be to keep the existing drip irrigation pipes. The investments required to realize the two solutions are shown in Table 6.

**Table 6. Capital costs for the two solutions**

| *Irrigation system using gasoline powered pumps (Existing solution)* | | *Irrigation system using electric pumps powered by photovoltaic panels (Proposed solution)* | |
|---|---|---|---|
| ***Equipment*** | ***Cost [€]*** | ***Equipment*** | ***Cost [€]*** |
| Filling fuel pump | 372 | Filling electric pump | 1,080 |
| Water tank | 13,990 | Water tank | 13,990 |
| Irrigation fuel pump | 703 | Irrigation electric pump | 980 |
| Fuel tank | 888 | PV panels | 2,208 |
| Transportation, installation | 500 | Inverter | 2,692 |
| | | Energy storage | 8,090 |
| | | Transportation, installation | 4,500 |
| ***Total cost*** | ***16,453*** | ***Total cost*** | ***33,540*** |

Source: Authors' own research.

To make a comparative analysis of the economic efficiency of the existing and the proposed solution, it is necessary to establish the hypotheses used. Over the last 5 years, during the period of study (April-September), the average price of gasoline has been about 1.37 €/l. The first hypothesis used in this study is a gasoline price of 1.37 €/l. This leads to a total cost of purchasing gasoline of about 5,555 €/year.

In addition to fossil fuel consumption (gasoline), according to the technical data provided by the manufacturer, the chosen gasoline pumps require an oil change after 25 hours of operation. Each pump requires 1.1 litres of oil. Over the course of a year, the two pumps run for approximately 3,176.25 hours, which means that approximately 140 litres of oil need to be purchased annually. The cost per litter of oil is €10, so the total cost will be €1,400.

**Table 7. Annual costs for the gasoline-powered irrigation system VS photovoltaic powered system**

| *Annual equipment operating expenditure* | *Irrigation system using gasoline powered pumps* | *Irrigation system using electric pumps powered by PV* |
|---|---|---|
| Fuel cost [€/year] | 5,555 | - |
| Oil cost [€/year] | 1,400 | - |
| Maintenance and repair cost [€/year] | 50 | 20 |
| ***Annual cultivation expenditure*** | | |
| Seed cost [€/year] | 1,655 | 1,655 |
| Fertilizer cost [€/year] | 1,567 | 1,567 |
| Fertilizer spreading cost [€/year] | 402 | 402 |
| Herbicide cost [€/year] | 1,145 | 1,145 |
| Herbicide spreading cost [€/year] | 804 | 804 |
| Seeding cost [€/year] | 502 | 502 |
| Harvesting cost [€/year] | 1,005 | 1,005 |
| Transport cost (fertilizer, herbicide, seeds) [€/yr] | 820 | 820 |
| ***Total annual expenditure [€/year]*** | ***14,905*** | ***7,920*** |

Source: Authors' own research.



According to Ciobotaru, the yield increase obtained by proper irrigation in an agricultural year under normal climatic conditions is 3 tons more per hectare. In a particularly dry year, the difference is 0 to 8-9 tons (Ciobotaru, 2023). Thus, two other hypotheses used in this study are the approximate yield of 9 tons/ha and the selling price of maize of 0.2 €/kg. At a price of 0.2 €/kg and an annual yield of 9,000 kg/ha, the total yield from the field will be 90,000 kg/year and the revenue will be about 18,000 €/year.

In both irrigation systems, the most used equipment are the pumps, both gasoline and electric. Depending on the environment, the integration into the system, the water quality or frequency of use, the pumps may have a shorter or longer lifespan. In general, according to some manufacturers, centrifugal suction irrigation pumps have a lifespan between 5 and 15 years. Regular maintenance, timely repairs and compliance with pump operating instructions contribute to prolong the lifespan of the pumps. Thus, in the present study, a period of 10 years was chosen as the period of analysis, which is considered as the average lifespan of the pumps. Also, the cash flow discount rate used in this paper is 5%. Table 9 shows the cash flows for fossil-fuel irrigation system. In this case, the cash flows generated led to a net present value (NPV) of €7,446.

**Table 9. Net Present Value for the irrigation system with gasoline powered pumps**

| *Year* | *Investment [€]* | *Operating expenses [€]* | *Income [€]* | *Cash Flow [€]* | *Actualization [€]* |
|---|---|---|---|---|---|
| 0 | -16,453 | 0 | 0 | 0 | -16,453 |
| 1 | | 14,905 | 18,000 | 3,095 | 2,947.62 |
| 2 | | 14,905 | 18,000 | 3,095 | 2,807.26 |
| 3 | | 14,905 | 18,000 | 3,095 | 2,673.58 |
| 4 | | 14,905 | 18,000 | 3,095 | 2,546.26 |
| 5 | | 14,905 | 18,000 | 3,095 | 2,425.01 |
| 6 | | 14,905 | 18,000 | 3,095 | 2,309.54 |
| 7 | | 14,905 | 18,000 | 3,095 | 2,199.56 |
| 8 | | 14,905 | 18,000 | 3,095 | 2,094.82 |
| 9 | | 14,905 | 18,000 | 3,095 | 1,995.06 |
| 10 | | 14,905 | 18,000 | 3,095 | 1,900.06 |
| ***NPV*** | | | | | ***7,446*** |

Source: Authors' own research.

In the case of the proposed solution of supplying the irrigation system with energy produced by photovoltaic panels, the investment is more than twice as high than in the case of the system with gasoline powered pumps. However, due to lower annual operating costs (zero fuel costs), the net present value is significantly higher at €44,295, as shown in Table 10.



**Table 10. Net present value for irrigation system using electric pumps powered by energy from photovoltaic panels**

| *Year* | *Investment [€]* | *Operating expenses [€]* | *Income [€]* | *Cash Flow [€]* | *Actualization [€]* |
|---|---|---|---|---|---|
| 0 | -33,540 | 0 | 0 | 0 | -33,540 |
| 1 | | 7,920 | 18,000 | 10,080 | 9,600 |
| 2 | | 7,920 | 18,000 | 10,080 | 9,142.86 |
| 3 | | 7,920 | 18,000 | 10,080 | 8,707.48 |
| 4 | | 7,920 | 18,000 | 10,080 | 8,292.84 |
| 5 | | 7,920 | 18,000 | 10,080 | 7,897.94 |
| 6 | | 7,920 | 18,000 | 10,080 | 7,521.85 |
| 7 | | 7,920 | 18,000 | 10,080 | 7,163.67 |
| 8 | | 7,920 | 18,000 | 10,080 | 6,822.54 |
| 9 | | 7,920 | 18,000 | 10,080 | 6,497.66 |
| 10 | | 7,920 | 18,000 | 10,080 | 6,188.25 |
| ***NPV*** | | | | | ***44,295*** |

Source: Authors' own research.

The payback period for the existing solution (irrigation system with gasoline pumps) is 6.338 years, which proves that the investment is recovered in about 6 years. For the proposed situation (irrigation system with electric pumps using photovoltaic panels), the results obtained show a payback period of 3.734 years, which proves that in this case the investment will be recovered in less than 4 years. In both cases, the payback is realized before the 10-year analysis period. Finally, given the fact that in this study the criterion for choosing the solution is the highest Net Present Value (NPV), it emerges that the solution with the highest economic efficiency is the one using photovoltaic panels.

In addition to the economic benefits, the reduction in gasoline consumption will lead to the elimination of carbon dioxide emissions. One litre of gasoline releases about 2,392 kg of carbon dioxide (EEA, 2017). Replacing fossil-fuel pumps with renewable energy systems, therefore, has led to the avoidance of about 9,700 kg of carbon dioxide emissions annually.

According to Raza et. all, in Pakistan the replacement of fossil fuel-based irrigation systems for about 8,093ha with photovoltaic panel powered irrigation systems totalling a capacity of 17.30 MW led to an annual saving of 6,600,000 litres of diesel and thus cost savings of about €2,481,145.66/year and avoidance of 17,556,000 kg of annual carbon dioxide emissions (Raza et al., 2021).

## Conclusion

Irrigation systems are an important pillar in maintaining and increasing the yield of maize crops, and the need for them has become increasingly apparent in recent years as climate change has intensified.

The analysis carried out in this paper highlights the economic and environmental benefits of supplying irrigation systems with photovoltaic panels. The results emphasize that the proposed solution (drip irrigation system powered by photovoltaic panels) has higher Net Present Value and shorter payback period than the existing case with a conventional fuel powered irrigation system. Also, the implementation of the proposed system leads to a reduction of carbon footprint by about 9.7 tons of $CO_2$. The use of renewable energy sources for the pumps is a solution that can be applied in any irrigation system, regardless of its type or size. The difference between the system studied and others is that in the case of drip irrigation, there is no need for high hourly flow rates and high pressures, which means lower electricity consumption. Thus, the analyses performed in this study can be used as a reference for the sizing of various types of irrigation systems.



The main limitation of this study is that the research was limited to the analysis of a single agricultural land located in a specific geographical area and its adaptation to certain particularities. Another limitation is to analyse the use of a single renewable energy source. Thus, in the future, the research can be extended by analysing a larger number of agricultural lands located in different locations and with different characteristics. Other renewable energy sources, such as wind turbines or even hybrid systems with several combinations of renewable energy sources, can also be used in the irrigation system.

## References

Călugăr, Roxana Elena, Varga Andrei, Vana Carmen Daniela, Ceclan Loredana Ancuța, Racz Ionuț, Chețan Felicia, Șimon Alina, Popa Călin, Tritean Nicolae, Russu Florin, and et al. (2024). Influence of Changing Weather on Old and New Maize Hybrids: A Case Study in Romania. *Plants 13*, no. 23: 3322. https://doi.org/10.3390/plants13233322.

Ciobotaru, Miruna-Ecaterina, (2023), The ongoing challenge. Why doesn't Romania irrigate to its potential? An Assessment of the Status of Irrigation in Romania through a Resilience Lens, *Euro-Atlantic Resilience Centre (E-ARC)*, Retrieved from https://e-arc.ro/wp-content/uploads/2023/08/Irigatii_Ciobotaru.pdf.

Conversion Guidelines - Greenhouse gas emissions -. (2017). EEA Grants Portugal. Retrieved from https://www.eeagrants.gov.pt/media/2776/conversion-guidelines.pdf.

Dobocan, Corina Adriana, Popescu Daniela, Topa Vasile. (2013). Water Consumption in Romanian Agriculture. *ProEnvironment 6, No. 13,* 46-51, Retrieved from https://journals.usamvcluj.ro/index.php/promediu/article/view/9107/7757.

Drienovski, R., Popescu Flavia, Ienciu Anişoara Aurelia, Manea D. (2016). Measuring water consumption in grain maize through indirect methods in the conditions of Sannicolau Mare, Timis County, Romania. *Research Journal of Agricultural Science*, 48(4), ISSN 2066-1843, 76-84. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173121850.

European Commission, Photovoltaic geographical information system. (2013). *re.jrc.ec.europa.eu*. Retrieved from https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#. (Accessed 15 Feb. 2025)

Grant Fiona, Sheline Carolyn, Sokol Julia, Amrose Susan, Brownell Elizabeth, Nangia Vinay and Winter Amos G.V. (2022). Creating a Solar-Powered Drip Irrigation Optimal Performance Model (SDrOP) to Lower the Cost of Drip Irrigation Systems for Smallholder Farmers, *Applied Energ*y, Volume 323, 119563, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2022.119563.

Gulve, Tejashri, Hake Ravikiran, Khaladkar Sagar, Walke Abhishek, Fartade Chandrakant, Korade Kailas. (2018). Design of drip irrigation system by renewable energy. *International Journal for Research in Applied Science and Engineering Technology*, Vol. 6, No. 6, 107-111 ref. 11, ISSN: 2321-9653, Volume 6, Issue VI, http://doi.org/10.22214/ijraset.2018.6021.

Micu, Dana, Elena-Ana Urșanu Popovici, L.-E. Havriş, C.-S. Dragotă. (2017). Heat stress-crop yields interactions under summer warming trends: insights for the southern cropping lowlands of Romania. *Romanian Journal of Geography*, 61(2), pp.169-192, Retrieved from http://www.rjgeo.ro/issues/revue_roumaine%2061_2/micu%20et%20al..pdf.

Mincu Florentina & Neculau Gianina. (2024). An experimental study on crop evapotranspiration in Romania. *Scientific Papers. Series A. Agronomy*, Vol. LXVII, No. 1, ISSN 2285-5785, 554-561. Retrieved from https://agronomyjournal.usamv.ro/pdf/2024/issue_1/Art70.pdf.

Niţu, Oana Alina, Gheorghe Marinela, Ivan Elena Ştefania, Bălan Mihaela. (2024). Optimizing drip irrigation yield in grain maize cultivation in Eastern Romania. *Scientific Papers. Series A. Agronomy*, Vol. LXVII, No. 2, ISSN 2285-5785, 307-313. Retrieved from https://agronomyjournal.usamv.ro/pdf/2024/issue_2/Art42.pdf.

Raghad, Ali Mejeed, Samah Shyaa Oudah, Rasha Yasen Abed. (2019). Design of solar photovoltaic pressurized drip irrigation pumping system at Al-salman District in Samawa Governorate, *International Journal of Power Electronics and Drive System (IJPEDS)*, Vol. 10, No. 3, pp. 1628-1637, ISSN: 2088-8694.10.11591/ijpeds.v10.i3.pp1628-1637.

Raza, Faakhar, Tamoor Muhammad, and Miran Sajjad. (2021). Socioeconomic and Climatic Impacts of Photovoltaic Systems Operating High-Efficiency Irrigation Systems: A Case Study of the Government Subsidy Scheme for Climate-Smart Agriculture in Punjab, Pakistan. *Engineering Proceedings 12*, No. 1: 36. https://doi.org/10.3390/engproc2021012036.

Siphiwe, Nxumalo Gift, Magyar Tamás, Tamás János and Nagy Attila. (2024). Modelling Soil Moisture Content with Hydrus 2D in a Continental Climate for Effective Maize Irrigation Planning. *Agriculture 14*, no. 8: 1340. https://doi.org/10.3390/agriculture14081340.

Stoyanov, Ludmil, Bachev Ivan, Zarkov Zahari, Lazarov Vladimir, and Notton Gilles. (2021). Multivariate Analysis of a Wind–PV-Based Water Pumping Hybrid System for Irrigation Purposes, *Energies 14*, No. 11: 3231. https://doi.org/10.3390/en14113231.

Vâtcă, Sorin Daniel, Stoian Valentina Ancuța, Man Titus Cristian, Horvath Csaba, Vidican Roxana, Gâdea Ștefania, Vâtcă Anamaria, Rotaru Ancuța, Vârban Rodica, Moldovan Cristina, and et al. (2021). Agrometeorological Requirements of Maize Crop Phenology for Sustainable Cropping—A Historical Review for Romania. *Sustainability 13*, no. 14: 7719. https://doi.org/10.3390/su13147719.