INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 8, Issue 1, 2017 pp.51-62
Journal homepage: www.IJEE.IEEFoundation.org

Environmental and energy problematic in the mediterranean irrigation regions framework

Laura Romero Marrero, Modesto Pérez-Sánchez, P. Amparo López-Jiménez

Hydraulic and Environmental Engineering Department. Universitat Politécnica de Valencia. Camino de Vera s.n. 46022. Valencia, Spain.

Received 29 July 2016; Received in revised form 5 Sep. 2016; Accepted 9 Sep. 2016; Available online 1 Jan. 2017

Abstract
Agriculture is a significant user of water and energy in Mediterranean coasts of Europe, such as Spanish Mediterranean regions. Water implications of such irrigations are well known, but also energy must be considered when environmental implications are analyzed. Apart from this, Mediterranean region has its particular problematic framework related to irrigation issues. Often, the availability of irrigation is determinant to the viability of farmers, and the energy implications must be considered when determining the feasibility of small and big farms, particularly in the Mediterranean regions, where the wide variety of customs in each group of irrigators and definitely, its specific weather conditions, typical of a semi-arid zone. All these aspects are analyzed in this paper, as a state of the art determination of problems and possible solutions in a regional scale. Some solutions presented in this paper can contribute with theoretical reductions of emission of greenhouse gasses until 174.10 tCO_2/year in pumped systems and 58.49 tCO_2/year in multipurpose systems.

Keywords: Irrigation systems; Mediterranean region; Semi-arid.

1. Introduction

The irrigation systems are designed so that they can fulfil certain requirements, without forgetting their economic issues (subsidies, low-medium costs): water must reach each irrigator with the pressure and flow demanded. To reach this goal, irrigation pressure systems must be implanted in the majority of cases, but it is not the most environmentally friendly method, as further discussed.

Under an energetic point of view, worldwide irrigation's modernization (particularly in the Mediterranean zone), has reduced water consumption per area, but this increase of hydraulic efficiency has led to an increase of energy consumption, which does not go hand to hand with the new politics of energy savings discussed, for example, in the Protocol of Kyoto.

Despite reducing water consumption, the lack of a good recovery costs policy in Mediterranean countries, such as Spain, explains why it is one of the less hydraulically efficient countries in the European Union [1].

Finally, the importance of sustainable management in networks will be discussed, and several saving water and energy strategies will be described both for gravity and pumped irrigation systems.

2. Water and energy in the irrigation framework

In the nineteenth century, the discovery of the steam engine and electricity [2], allowed the modification of the relationship between man and water and energy: the potential energy of water could be used through a turbine, transforming mechanical energy into electricity and water could be transported over long distances or higher levels than the point of extraction by using hydraulic pumps.

Currently, this relationship has evolved such that from the point of view of the environment and the new concept of sustainability, limits should be introduced in such a relationship, and these will be discussed in this article, as water uses change differently, as indicated in Figure 1.

As for the pressurized irrigation systems, these have developed since the mid-70s, as well as water purification and water treatment. Energy demand for applications of irrigation has grown every year since then, and is currently one of the main uses of water linked to energy (49%) together with hydroelectric production (30.6%), and the highest (92%) in terms of water consumption. Furthermore, in recent years the use of energy in this sector has grown very rapidly.

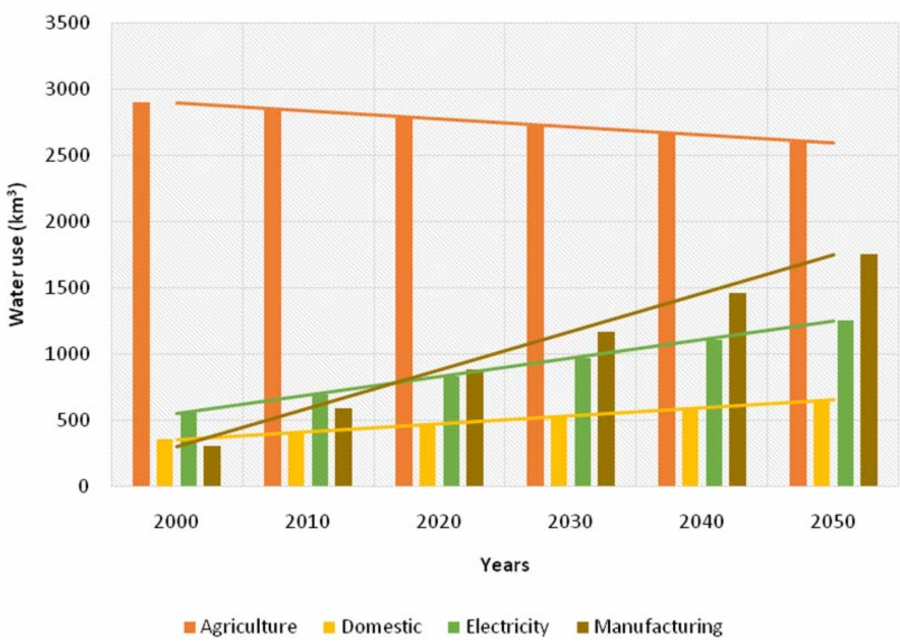

Figure 1. Use of water for different purposes [3].

New irrigation systems were implemented in less productive land, located at greater distances and heights of the extraction point, requiring higher energy inputs needed for lifting, transporting and distributing the water [2].

In 2002, Spanish Government approved the National Irrigations Plan, actually in development because different extensions have been given. This Plan has as objective to change irrigation system by transforming the gravity irrigation systems by pressurized systems, fundamentally drip irrigation systems. Autonomic Governments of the Spanish Mediterranean zone developed their actuation's plans rapidly during firsts years (2002-2008) due to extreme climatic conditions (e.g. high temperature, low and irregular precipitations) that these regions suffer.

The development of plans preciously cited involve economic public support for irrigation, based on the modernization of irrigation. These actuations have caused that a 48.53% of the irrigated surface in Spain have located irrigation systems, and this number of irrigated hectares is very high if it is compared to the worldwide surface, where only 3% is irrigated by drip systems [4]. Particularly, in the Valencian Community (East Mediterranean region in Spain) this surface reaches a value up to 63%. Therefore, these plans have improved water efficiency by 21%, and although the irrigated area has increased by 12%, energy consumption has increased by 33%.

As for the source of irrigation water uses, traditionally irrigation with surface water has not needed external power supply in the distribution, but with the development of pressurized distribution systems, the demand of an external energy input has been born in the distribution of circulating flows. Likewise, the average values of energy intensity of irrigation number from 0.02 kWh/m^3 for gravity systems with surface water, to 0.68 kWh/m^3 for localized irrigation using groundwater, or to 4 kWh/m^3 for crops that use desalinated water. According to studies of the Institute for Diversification and Saving of Energy (IDAE) [5], the drip irrigation needs an average value 2 kW/ha of installed power.

In Spain, the water consumption distributed 80% in irrigation, 15 % in supply and 5% in the industry, being the annual volume used by the agriculture 16344 hm^3 [6], and the distribution cost equal to 1285 million of euros in 2012 (It is 20% of the total cost of the water supply service in Spain) [7].

Similarly, as for the cost of energy, in Spain the price is set on the market since 2007. The total price of energy has increased due to the increase of the permanent cost of installed power although the price of generated energy is cheaper in some intervals of time. Therefore, to carry out the recovery cost principle of water services defined in the Water Framework Directive, an increase of the cost of energy needed for extraction of groundwater for irrigation (or those extractions where an energy input is needed) is required. So, this need to define high energy prices translate into an obligation to improve energy efficiency in all phases of irrigation: design, maintenance and management.

As depicted in Figure 2, since 1990 (from 1950 to 2013) the modernization of irrigation, has contained water demand, improving water efficiency but worsening energy efficiency, due to the need to provide more energy to the system. For the 1950-2013 period, water efficiency improved by 23% while energy efficiency worsened by 69%.

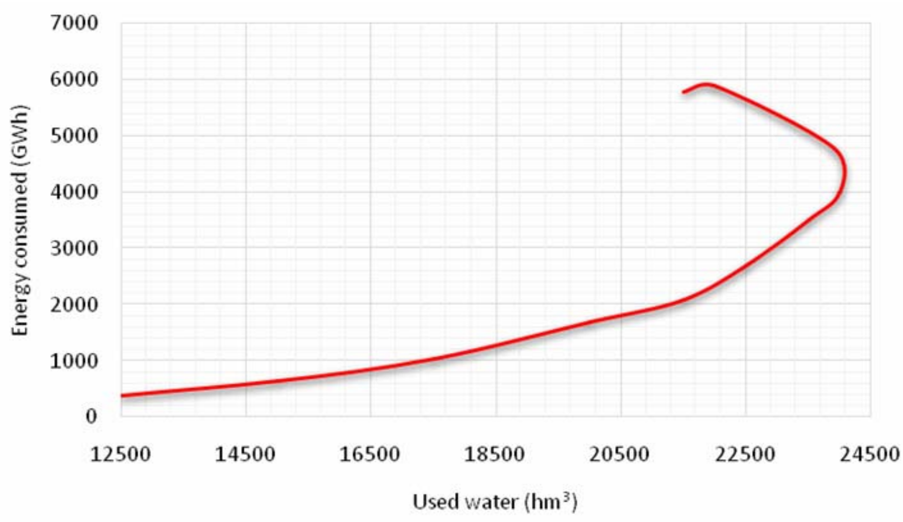

Figure 2. Consumed energy for irrigation purposes from 1950 to 2013, adapted from [2].

Effects of climate change along with other degradation of our environment have generated new lines of action that could be applied to water management, and aim to reduce the exploitation of natural resources (increasing water efficiency) and the impact on the environment (e.g. improving the fertirrigation's application) such as: the ecological, water and energy [8] footprints, virtual water consumption and use of virtual power. In this sense, various regulations or agreements have been issued in relation to water and energy, such as the Water Framework Directive, where the need to put less pressure on water resources and reducing diffuse pollution is defined. Another example is the Kyoto Protocol, where the need to improve efficiency and increasing use of renewable energy is defined.

To continue in this line, if Spanish irrigation wants to continue growing, a renounce to unprofitable or inefficient irrigation is needed. In turn, water and energy efficiencies must increase in the different phases of the water cycle: abstraction, distribution and use; as well as improving the regulation of hydric resources for ensuring supply capacity during droughts, but avoiding increasing energy demands and exploitation of resources which are very expensive to obtain (e.g. desalinization).

3. Sustainable management of water networks

To mitigate water stress and to embrace the concept of sustainability, it is necessary to implement an efficient water management [3], in order to improve efficiency, encourage water saving and promote reusing of water. As water demand is growing as well as climate change is worsening, a more efficient use of water is needed and so these actions must be taken:

- The cost recovery principle (Water Framework Directive) must be applied to encourage users to save water and improve efficiency. In case of irrigation networks, it is necessary to subside the poorest without having to do so with the whole service, but they should be given in a way that they motivate water saving [9]. This can be reached by rewarding the production obtained per meter cubic of water used, instead of distributing the subsidies without taking into account production. Finally, it must be ensured that all the money users pay is invested in maintaining and improving these services.
- Old or inefficient infrastructures must be renewed. This will reduce water leaks and so reduce energy and water consumption, as it is discussed in the next chapters.
- Farmers must be educated to be concerned for environmental issues and knowledge must be increased by incentivizing research in universities or institutions.

Regarding to available data for urban networks, northern countries have a low per capita water consumption despite that water resources abound [1]. This is because all the costs generated by the management of the sustainable service is recovered by users paying a high price for it. Also, in the countries of southern Europe, such as Spain, water stress is much higher and yet subsidized tariffs are more frequent and thus the maintenance of the hydraulic infrastructures is much worse. This difference between countries is due to the fact that the northern countries are aware with an efficient use of water, and for this it is necessary to force the user to abide the cost recovery principle. This means that managers will strove to improve their management and users will contain their spending. As depicted by Cabrera [1], the greater cost recovery the greater the efficiency.

Comparative studies between productivity in irrigation depend on the source of water and therefore they are based on the price paid by the farmer evidenced this. In Spain, while in 2000 for surface water the Andalusian farmer paid 0.01 €/m^3, for groundwater he paid ten times more due to the cost of energy[10]. And, as shown in Table 1, the higher the price of water, the higher the productivity of crops.

Table 1. Agricultural productivity in Andalucia, Spain, based on the waters' origin [10].

Water origin	Surface water	Groundwater
Productivity (€/m^3)	0.60	2.42
Efficiency (m^3/Ha)	4360	4854
Water/work unit (m^3/WU)	15189	43407

Even in different Mediterranean Zones in Spain, the prices are different in function of water origin and localization. In Vega Baja Region (near to Orihuela, Alicante) the water price can be 0.15 €/m^3 if the water origin is Segura's river, 0.27 €/m^3 when the origin is Tajo-Segura Transfer, 0.20 €/m^3 for water originating from waste treatment plant and 0.29 €/m^3 if the water is extracted to groundwater. In the Regions of Vinalopó River, when almost all water come from groundwater, the price which depend on piezometric level oscillates between 0.15 and 0.40 €/m^3. In the Northern Regions of Alicante, where the water origin is groundwater, the price is around 0.15 and 0.25 €/m^3.

At the same time, the application of the cost recovery principle does not necessary increase the bill but it changes the method of payment [1]. Thus, the costs that sustainable management of water implies should be abided entirely by users or part by users and partly through taxes. This second approach to the payment of water infrastructure favors to use waste water, where the Administration should include part of the costs to transport water since treatment plant to irrigation areas in the drinking water bill. This decision would favor reusing of this resource and avoiding its discharge in streams, once the water has been purified as occurs actually, where a high percentage of purified water are not used to irrigation because the necessary infrastructures to connect water treatment plant and irrigation areas are not developed.

Finally, it should be remarked that desalination is not the solution to reduce the shortage of water, as it carries a high energy expenditure which causes an expensive price (around 60 c€/m^3) to be used in the agriculture. Also, the desalinization causes emission of greenhouse gases and therefore climate change. Yet, nowadays, it is the most applied solution to address the problems in the Spanish supply networks, but its use in agriculture is today unviable. Therefore, the European Union sees this as the ultimate solution to be applied to address the shortages [1], being shown in Figure 3 below the vicious cycle that is encouraged by the establishment of desalination plants.

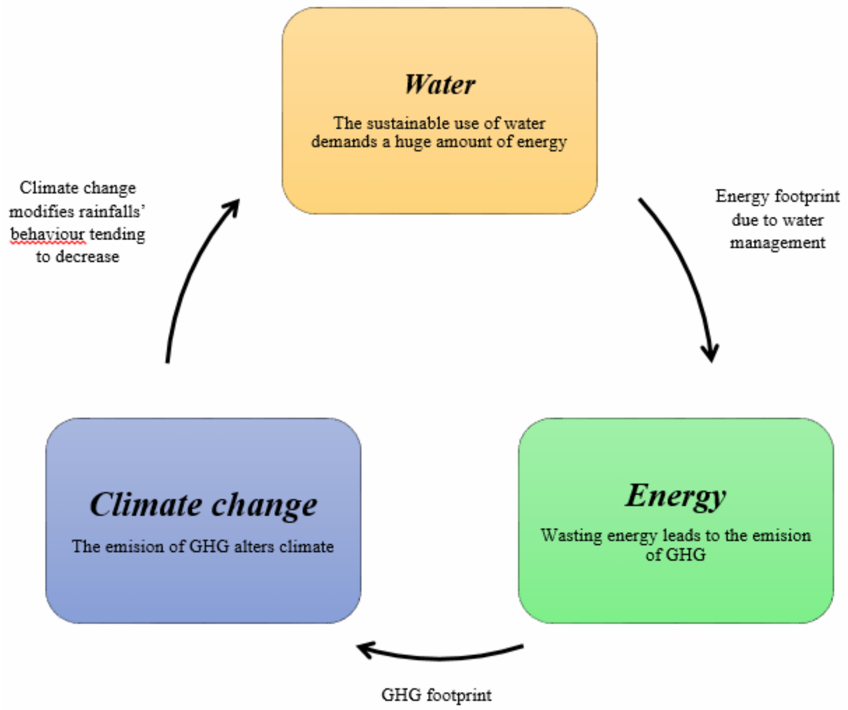

Figure 3. Water-energy-climate change in Mediterranean regions adapted from [1].

4. Energy audits and irrigation water leaks

Regarding to the irrigation network performance, most of the irrigation systems in Spain are inefficient in terms of hydraulic and energetic efficiency, by lack of an efficient management and of the implementation of new technologies for energy and water saving. As explained in some articles [11-15], minimizing the energy costs in irrigation networks is very important in on-demand irrigation networks with installed pumped systems in which the energy expenses are very high in comparison with the other types of irrigation management in terms of installed power. These energetic costs do not exist in pressurized systems, where flows are gravity distributed.

In these articles a methodology is elaborated to minimize energy costs in the pumping station and was validated in an on-demand irrigation network located in Tarazona de La – Mancha (Albacete, Spain), where several scenarios were developed to determine the starting time for each irrigation event and hydrant [12]. Other researches develop strategies to minimize energy consumption [13, 14] and operational actions to improve energy efficiency focused on developing an energy audit for the network, [15] to check whether the network loses too much energy. Under this point of view, many actions can be done to improve energy consumption, such as reducing leaks and friction losses.

So, a lot of energy can be wasted as a result of network leakages [16], not only from the energy leaving the system through leaks, which can be quite significant depending on the energy footprint of the produced water, but also the energy needed to overcome additional friction losses created by higher circulating flow rates through the pipes or dissipated energy in compensation tanks or intermeddle reservoirs.

Identifying the end uses of the energy entered in networks helps managers to define a performance assessment system that characterizes the network from an energy perspective through context information items and evaluates its energetic performance. Therefore, it is necessary to know where the provided energy in the system is used (i.e. friction losses, consumed by pumps, losses in pumps, losses in pressure reduction valves, losses in leakages, needed to irrigate). The knowledge of these values allows to determine the network's performance and to develop improvement strategies.

This can be done with the energy audits before mentioned, which can also be supplemented with water and energy price information, as well as estimates of carbon and greenhouse gases impacts for the sources and amounts of energy use, in order to form part of a more holistic evaluation of system performance improvement options (e.g. cost-benefit analysis framework). As a matter of fact, these tools could easily be used from a regulatory or administrative perspective to create incentives for a more efficient use of energy in water distribution.

The energy audit, such as associated indicators, requires a previous water audit and so, it requires the network's control with flow measurement elements. These measurements give us the volumes needed to calculate performance indicators of the network which have been widely used in water balances but do not represent the real physical state of the network. For example, when consumption by irrigators increase, so does the networks efficiency and this does not represent reality as water leaks may continue to be the same (if pressures continue to be the same). Consequently, to correctly evaluate water leaks, relative indicators should be used [17]. These indicators are defined by the four parameters which directly affect water leaks: pipe length, pressure, hours of service and number of connections to the distribution network.

At the same time, several strategies can be implemented to reduce water leaks: repair or substitute old pipes, installation of systems to achieve an active control of leaks and pressure regulations. To achieve an active control of leaks, several systems can be installed such as acoustic methods or SCADA (Supervisory Control and Data Acquisition), which allows a real-time system monitoring and the detection of possible anomalies in the network. Under the pressure point of view, these must follow a uniform pattern to avoid an increase in pipe's fissures or the deterioration of water quality due to pressures in pipes under the atmospheric pressure giving rise to the introduction of pathogens.

Leaks are closely related with water prices. Water networks which are subsided by the government and have very low water prices, are unable to recover costs from network's management and investment and so are unable to invest money in reducing water leaks.

Finally, these are the main structural operations to reduce energy consumption and leaks:

- To recover or reduce the topographic energy installing Pumps as Turbines, -to recover energy- or dividing the system in sectors with different geometric levels (energy platforms) with different energy requirements, to reduce the topographic energy. The decoupled energy sectors will be fed with different pumps (with head – flow curves tailored in accordance with each platform's needs). Another alternative is to supply additional energy to highest sectors with booster pumps [5].
- To improve old designs. Networks have been traditionally designed on the back of energy efficiency criteria, e.g., tanks have been built at the highest level of the city to provide adequate pressure to any demand point. But this increases the topographic energy at the efficiency's expense. Minor changes, such as water direct supply (without head tanks) instead of the indirect one (throughout head tanks) can save a lot of energy and so a lot of money [18].
- To use more efficient pumps [19], improving the best efficiency points (BEP) through the installation of variable frequency motor drives which allow the regulation of the rotational speed of the pump, adjusting it to the minimum necessary head for each period, depending on the circulating flow and ensuring the minimum pressure condition in the users' plot.

5. Saving water and energy strategies

5.1 Gravity irrigation systems

The belief that all gravity irrigation systems must be transformed into pressure ones must be overpassed: it is possible and even ecologically desirable, to improve the efficiency of water use in irrigation by gravity [2]. Therefore, this irrigation system can persist in the plantations which require low irrigation endowment (e.g. almond tree, olive tree, pistachio tree) or when these are located in places with high and cheap availability of the resource. However, this type of irrigation must avoid in intensive crops to reduce the soil and aquifer contamination by fertilizer (e.g. nitrates).

In the process of modernization of distribution networks, it is common that not all irrigators have changed their farm irrigation system, having still a gravity irrigation [20]. Despite of this, to avoid the problem of canals and ditches maintenance in the gravity distribution system, all users are supplied through the pressure distribution network, so that in the plot-off intakes, gate valves are installed. From the energy point of view this system is very inefficient, since the energy supplied is wasted, so it is best to motivate the installation of pressurized irrigation throughout the irrigable area, as the maintenance of open channels increases exploitation costs and so, reduces hydraulic efficiency.

5.2 Pumped irrigation systems

In the pressurized irrigation systems three situations can occur in function of the topography and localizations of the reservoirs (Figure 4).

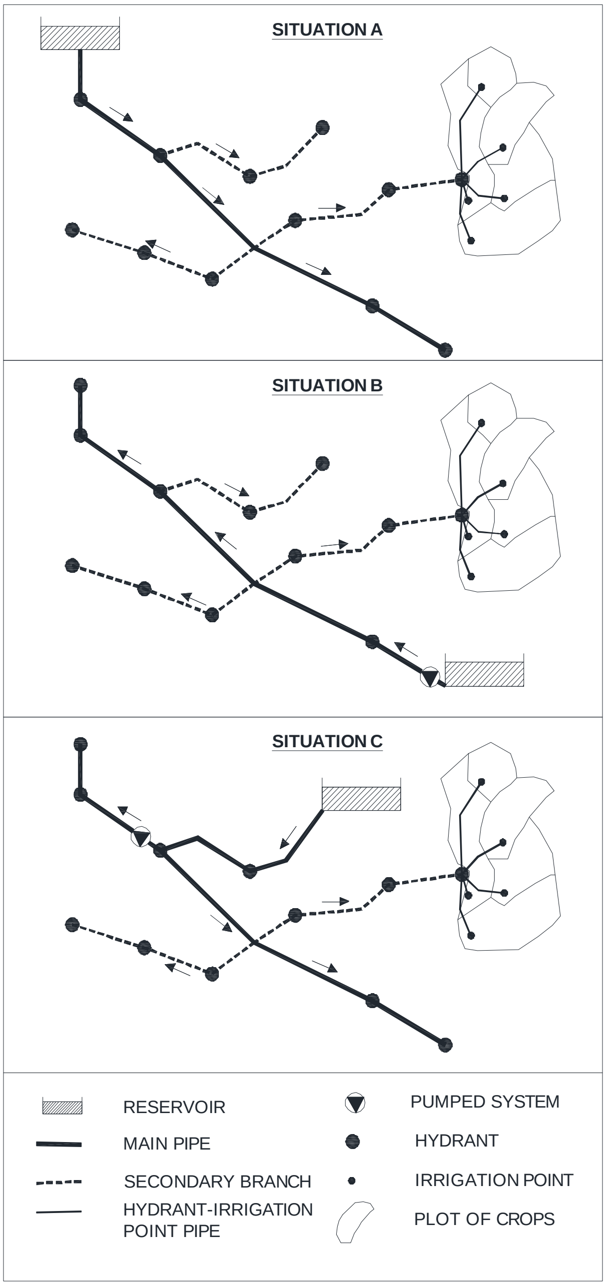

Figure 4. Operation schemes.

a) Situation A. All circulating flows are distributed by gravity through pipes until irrigations points, taking advantage of the difference of levels between reservoir and consumption points. In this cases, the used energy is accumulated in the reservoir, being its distribution free in economic terms but not energetic because to adapt the service pressure to user, pressure reduction valves (PRVs) must be installed in one or varies places of the network (e.g. branch, hydrant or irrigation points). In this situation, the cost (economic and energetic) of water storage depend on water origin.
b) Situation B. Pumped systems are necessary in the supply of the consumption nodes because irrigation points are higher than reservoir. This situation is usual in plain zones where the installation of reservoir with sufficient level is impossible.
c) Situation C. This is the mix between situation A and B. In these cases, part of the network is distributed by gravity and the rest with pumped systems.

From an energy point of view, the operation type of the network is very important to design the network. If the network operates by gravity in its entirety, designs on-demand where the user has total liberty to decide the irrigation moment are the best solution in irrigation communities, as this design does not suppose a ‘extra’ consumption of energy. Otherwise, where network completely o partly operates with

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

pumped systems (Situation B or Situation C), the design of these networks must be analyzed with energetic and economics criteria, considering the installed power and the frequency of circulating flows. In this case, a design on-demand in the months with low and middle needs can be considered, choosing a scheduled rotational management for the months of high needs as long as the water manager agrees. This design option can resolve the economic problems due to fixed power terms by high installed power in the pump groups.

However, the designer must keep in mind that the networks with scheduled rotational management are cheaper when the number of scheduled is high. If the network is projected with less of four turns, only initial inversion is smaller in the final pipes. In the same way, if a high number of turns is considered, the obtained network is characterized by a high rigidity in the farmer's use and hypothetical changes of crops type taking account that useful life of a network is upper to thirty years. Nevertheless, collective irrigation networks are designed to work on-demand [21] with different levels of supply guarantee, and so water supply is guaranteed during peak periods.

At the same time, in case of pressurized water distribution networks operating on-demand, the branched network can experience high and continuous fluctuations in flow depending on the number of the hydrants being simultaneously opened. Mainly, this fluctuation of flows is due to farmer's habits (i.e. irrigation endowment, maximum days between irrigations, irrigation duration) which determine opened probability of the irrigation points, being variable in each consumption node [22].

5.2.1 Pumped irrigation systems

Under an energy cost point of view, when pumped system exists in the network, energy efficiency is usually higher in rotation schedule networks if sectors are properly selected, as the organization of the irrigation events is better and demand is exactly known. In the case of on-demand irrigation networks, these are not so clear by uncertainty in the demanded flow because the number of open irrigation points are not known. In addition, pumping heads are usually more adjustable to the real requirements in the case of rotation schedule networks than in on-demand ones, where their stochastic nature leads to oversizing of the network and pumping station in order to ensure supply during the period of maximum flow demand. There are many different methods to develop the grouping of hydrants into sectors with the aim of energetically optimize the management of irrigation networks. By using an adequate algorithm, the system can achieve significant energy savings by adopting alternative management measures such as semi-arranged demand, by dividing the network into sectors or by improving the pumping station allowing them to operate in the most efficient manner [13, 14]

Also, rotation schedule networks are more susceptible to suffer an inefficient management than on-demand networks because of the lack of availability of tools for managers when selecting the configurations of open hydrants and choosing the proper pumping head for each of these configurations. This problem can be previously solved by using a hydraulic simulation model of the network and by implementing methodologies to calculate the appropriate head of the system for each of these configurations.

Thus, many Spanish irrigation systems [19] have opted for the installation of valves which partial closure has restricted the flow pumped by the pumping station, a system that involves high energy losses. It is therefore preferable to install, as stated above, variable speed pumps or multiple pumps in parallel [5].

The network sectorization, so that the water distribution is done by sectors with the same energy demand, is a measure which allows the water to reach the plot-off intake with the required pressure, avoiding overruns of energy and thus avoiding the installation of pressure reducing valves [20]. So, the use of these valves should be limited to those distribution networks operated by gravity where the existing static pressure generates overpressure at the entrance to plot due to the difference in level between it and the head of the distribution network.

In Table 2, the results for operational actions applied in pumping stations are shown for three pressurized irrigation networks. As we can see, by applying the adequate tool, bombs can be regulated to work for less time or in their best efficient point, and so energy savings increase in the values which are shown in the table. This energy savings, according to Spadaro [23] energy savings and recovery energy can contribute with a theoretical average reduction of greenhouse gases emission of 730 gCO_2/kWh if this is compared to non-renewable energy solutions (e.g., coal and gas). Therefore, according to Table 2, the energy savings contributes with a theoretical reduction emission between 3.20 tCO_2/year and 174.10 tCO_2/year in function of the analyzed network.

Table 2. Comparative of three case studies [12, 13, 15], where tools are applied to change the regulation of the pumping station of three pressurized irrigation networks, in order to reduce energy consumption.

Localization	Type of Network	Energy Consumed (kWh/day)	Methodology applied to save energy	Energy Saved (%)	Energy Saved (kWh/day)
Tarazona (Albacete, Spain)	On-demand pressurized irrigation network	150	Operational actions: improving regulation of the pumping station	4-8	12
Cap de Terme (Villarreal, Spain)	Rotation schedule pressurized irrigation network	6600	Operational actions: improving regulation of the pumping station (including changes of turns and pumps' speed)	28	1848
Picassent (Valencia, Spain)	Rotation schedule pressurized irrigation network	1800	Operational actions: improving regulation of the pumping station	36.3	653,40

5.2.2 Pumps as turbines in irrigation networks: optimal energy recovering

In pumped systems, the objective is to reduce energy consumption in the distribution flows. However, in pressured networks distributed by gravity, the reduction of pressure is necessary, avoiding irrigations points located in low levels to present high service pressure. This pressure is dissipated by PRVs, being this process totally inefficient from energetic point of view. Therefore, different researches have proposed the use of pumps working as turbines (PATs) [24-26]. These hydraulic machines due to low investment cost, can be a sustainable solution to install in water distribution systems (supply and irrigation), generating clean energy where PRVs are installed at this moment [27, 28] but ensuring the minimum service pressure to the user, as these systems are distribution networks and the electrical generation (to sell or self-consumption) is not critical.

To install PATs in pressurized systems, previously its simulation is necessary because to know flows and pressure along the time in the different lines and nodes of the network allow determining the places where recovery energy is maximum. This maximization can be performed through optimization methods, being the most used simulated annealing [29], once circulating flows along the time have been determined. Although these analyses must be particularized in each network such as in the Vallada's irrigation network (Figure 5), the provided energy in the network is equal to 274 MWh/year, 6.2 MWh/year is dissipated by friction, non-recoverable energy is equal to14.5 MWh/year and 75.42 MWh/year is theoretical recoverable energy, being the energy required for irrigation equal to 178.1 MWh /year [22].

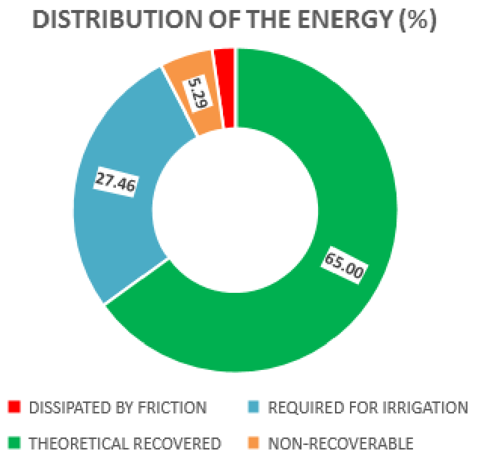

Figure 5. Distribution of energy in Vallada's irrigation network, adapted from [22].

6. Conclusions

Spain has an important quantity of irrigated hectares which approximately this surface represents 19% of the worldwide drip irrigation, from a technical point of view, it may be of technical interest to make a potential analysis of energy recovery in pressure irrigation networks, particularly in Mediterranean regions, where water scarcity and energy implications are very important. Furthermore, the energetic cost that irrigation pressurized supposes (and therefore environmental cost), the water managers must take decisions to improve the energetic efficiency in their distribution networks. This improvement will contribute to reduce the emission of greenhouse gas, obtaining more sustainable exploitations.

To carry out this improvement, previously, water managers must install measurement elements in the network to develop:

a) Energy audit that its analysis allows to know the performance of different parts of the network (i.e. leakages, pumps, friction) and margin of improvement. When weak points of the network are known, water managers can take the right decisions.
b) Models which allow performing simulation and calibration of the network to develop analysis, where the improvements propose in the energy audits can be verified.

Therefore, in case of networks already installed, with a proper hydraulic model and the adequate tools for analyzing the energy efficiency at pumping stations, an efficient management of the irrigation network can be obtained and energy consumption may decrease, obtaining large energy savings. These reductions in case study analyzed can contribute with reduction emission between 3.20 tCO_2/year and 174.10 tCO_2/year.

In this sense, in gravity pressurized systems, the installations of PATs can contribute to increase the efficiency in these networks taking advantage the energy dissipated by PRVs. This energy could use as self-consumption or be sold. Particularly, the development of this recovery strategies in Vallada's network can recover 65% of the provided energy considering the installation of ideal machines with a potential saving of non-renewable energy resources of CO_2 54.89 t/year.

Acknowledgements

Authors greatly acknowledge financial support from the "Catedra Aguas de Valencia" in the grant "Modelling Irrigation Activity" for the first author of this contribution.

References

[1] Bru C. et al. Agua, Historia y Sostenibilidad, un trinomio complejo de armonizar en los países mediterráneos. El contexto de la gestión del agua.
[2] Corominas J.Agua y Energía en el riego en la época de la sostenibilidad. Ing del Agua. 2010;17(3).
[3] Cabrera E. Urban and Industrial Water Use Challenges. La gestion sostenible del agua urbana y sus retos. Chapter 13.
[4] FAO. Aquastat 2015. http://www.fao.org/nr/water/aquastat/data/query/results.html?regionQuery=true&yearGrouping=SURVEY&showCodes=false&yearRange.fromYear=1958&yearRange.toYear=2017&varGrpIds=4250%2C4251%2C4252%2C4253%2C4257&cntIds=&regIds=9805%2C9806%2C9807%2C9808%2C9809&edit. Accessed June 9, 2015.
[5] Instituto para la Diversificación y Ahorro de la Energía. Ahorro y Eficiencia Energética en Agricultura de Regadio. Madrid, Octubre 2005.
[6] Seoane P, Allué R, Postigo MJ, Cordón MA. Boletín Mensual de Estadística. Octubre 2013. Madrid, Spain; 2013
[7] Maestu J, del Villar A. Precios Y Costes de Los Servicios Del Agua En España. Vol Centro de Madrid, Spain; 2007. http://hispagua.cedex.es/sites/default/files/especiales/Tarifas_agua/precios_costes_servicios_ agua.pdf.
[8] Daccache A. et al. Water and energy footprint of irrigated agriculture in the Mediterranean region. Environmental Research Letters; 9 (2014) 124014 (12pp).
[9] García Molla, M.; Ortega Reig, MV.; Sanchis Ibor, C.; Avella Reus, LF. (2014). The effects ofirrigation modernization on the cost recovery of water in the Valencia Region (Spain). WaterScience and Technology: Water Supply. 14(3):414-420.
[10] Coromias J. El papel económico de las aguas subterráneas en Andalucía. Fundación Marcelino Botín. Madrid. 2000.

[11] Rodríguez Díaz et al. Detecting Critical Points in On-Demand Irrigation Pressurized Networks – A New Methodology. Water Resour Manage (2012) 26:1693-1713.
[12] Moreno, M. A., Planells, P., Córcoles, J. I., Tarjuelo, J. M., & Carrión, P. A. (2009). Development of a new methodology to obtain the characteristic pump curves that minimize the total cost at pumping stations.Biosystems Engineering, 102(1), 95-105
[13] Jiménez-Bello, M.A., Royuela, A., Manzano, J., Prats, A.G., Martínez-Alzamora, F., 2015. Methodology to improve water and energy use by proper irrigation scheduling in pressurised networks. Agric. Water Manag. 149, 91–101.
[14] Prats, A.G., Picó, S.G., Alzamora, F.M., Bello, M.Á.J., 2011. Random Scenarios Generation with Minimum Energy Consumption Model for Sectoring Optimization in Pressurized Irrigation Networks Using a Simulated Annealing Approach.
[15] Cabrera E. et al. Towards an energy labelling of pressurized water networks. Procedia Engineering 70 (2014) 209-217.
[16] Cabrera E. et al. Energy Audit of Water Networks. Journal of Water Resources Planning and Management, 2010, 136(6): 669-677.
[17] Cabrera E. Una aproximación a la problemática de las pérdidas de agua en redes urbanas. Universidad Politécnica de Valencia.
[18] Gómez E. et al. Direct and indirect water supply: an energy assessment. Procedia Engineering 119 (2015) 1088-1097.
[19] Servicio Integral de Asesoramiento al Regante et al. Eficiencia energética en instalaciones de riego. Hoja Informativa, Abril 2009, Nº17.
[20] Instituto para la Diversificación y Ahorro de la Energía. Ahorro y Eficiencia Energética en las Comunidades de Regantes. Madrid, Abril 2008.
[21] Moreno M.A. Energy efficiency of pressurised irrigation networks managed on-demand and under a rotation schedule. Biosystems Engineering 107 (2010) 349-363.
[22] Pérez-Sánchez, M., Sánchez-Romero, F., Ramos, H., López-Jiménez, P., 2016. Modeling Irrigation Networks for the Quantification of Potential Energy Recovering: A Case Study. Water 8, 1-26.
[23] Spadaro, J.V.; Langlois, L.; Hamilton, B. Greenhouse Gas Emissions of Electricity Generation Chains: Assessing the Difference. IAEA Bull. 2000, 42, 19-28
[24] Carravetta, A., Del Giudice, G., Fecarotta, O., Ramos, H.M., 2012. Energy Production in Water Distribution Networks: A PAT Design Strategy. Water Resour. Manag. 26, 3947–3959.
[25] Carravetta, A., Del Giudice, G., Oreste, F., M., R.H., 2013. PAT Design Strategy for Energy Recovery in Water Distribution Networks by Electrical Regulation [WWW Document]. Energies.
[26] Ramos, H., Borga, A., 1999. Pumps as turbines: an unconventional solution to energy production. Urban Water 1, 261-263.
[27] Ramos, H., Mello, M., De, P.K., 2010. Clean power in water supply systems as a sustainable solution: from planning to practical implementation. Water Sci. Technol. Water Supply 10, 39–49.
[28] Ramos, H.M., Vieira, F., Covas, D.I.C., 2010. Energy efficiency in a water supply system: Energy consumption and CO2 emission. Water Sci. Eng. 3, 331-340.
[29] Samora, I., Franca, M., Schleiss, A., Ramos, H., 2016. Simulated Annealing in Optimization of Energy Production in a Water Supply Network. Water Resour. Manag. 30, 1533-1547.

Laura E. Romero Marrero received her BSc in civil engineering from the University of Las Palmas de Gran Canaria and is currently taking her studies at the MSc Hydraulic and Environmental Engineering in the Universitat Politècnica de València. She is participating in a scholarship with the Department of Hydraulic and Environmental Engineering and Aguas de Valencia, where general problems in each phase of an irrigation system are being analyzed.
E-mail address: lauraerm@hotmail.com

Modesto Pérez-Sánchez is M.Sc. in Agricultural Engineering and M.Sc. in Hydraulic and Environmental Engineering from the Universitat Politècnica de València (Spain). Currently, He is Assistant Professor and Researcher in the Hydraulic and Environmental Engineering Department at the Universitat Politècnica de València, where is developing his PhD. He has been involved in big engineering projects related to water management in Spain and He has a lustrumof experience in research and teaching in Engineering fields, always related to hydraulic topics. He has participated in different as co-author in different publications and conferences about Hydraulic an Environmental Engineering.
E-mail address: mopesan1@upv.es

P. Amparo López-Jiménez is PhD in Industrial Engineering, Associate Professor in the Hydraulic and Environmental Engineering Department at the Universitat Politècnica de València. She is currently the Associate Director of the Hydraulic and Environmental Engineering Department of Universitat Politècnica de València. She has more than a decade of experience in research and teaching in Engineering fields, always related to hydraulic topics. She is author and editor of several publications about Hydraulic an Environmental Engineering and Flow Dynamics. She has participated in national and international R&D projects and co-organized International Seminars and Networks. She is an experienced University Teacher, an active researcher and a former practicing engineer.
E-mail address: palopez@upv.es