REDAWN – Reducing Energy Dependency in Atlantic area Water Networks

PROJECT REPORT

WP3.1 report Business Models & Business Cases for Micro-Hydropower Capitalisation

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REDAWN
Reducing Energy Dependency in Atlantic Area Water Networks
Interreg
Atlantic Area
European Regional Development Fund
EUROPEAN UNION

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List of Abbreviations

AA	Atlantic Area
GHG	Greenhouse gas
FIT	Fee-in-Tariff
PAT	Pump as turbine
PV	photovoltaic
MHP	Micro-hydropower
SHP	Small hydropower
WP3	Work Package 3
WP4	Work Package 4
WP5	Work Package 5
WWTP	Wastewater Treatment Plant

1. Executive Summary

As part of the REDAWN project, Work Package 3 (WP3) has focussed on the capitalization of the market for micro-hydropower (MHP) energy recovery technology in the water networks in the Atlantic Area (AA) of Europe. This work package has been supported by the development of several business cases, focusing on: the 3 pilot plants implemented under the project REDAWN, within the WP7; the research and assessment of the energy recovery potential in water networks performed under WP4; and the results obtained in WP5, focusing on the economic and environmental impacts of the project. In addition, this WP3 has explored the potential market for MHP in the European AA, developing then a commercialization model as well as the capitalization of the results of the project in policy terms.

The objective of the business cases presented here in the WP3.1 Report was to show the potential benefits of the integration of the MHP technology for energy recovery, for the different stakeholders in the water industry sector, both in economic and environmental terms. On the other hand, the business model tried to summarise the potential market for the companies involved in the design and installation of MHP technology.

Different business cases have been compiled, based on some historical energy recovery sites, along with the 3 real pilot plants developed under the REDAWN project, and finally, the description of some other theoretical cases, exploring the potential of the MHP technology in the different countries and sectors included in the analysis: drinking water, wastewater, process industry and irrigation. On the other hand, the business model section reflects the potential market estimated on the basis of the sites previously analysed for each of the sectors, in the set of countries, with a population-based extrapolation of the MHP potential results. In this same section, an overview of the customers segments and current companies related to the MHP technology is presented, as well as the general legal framework of hydropower in the AA.

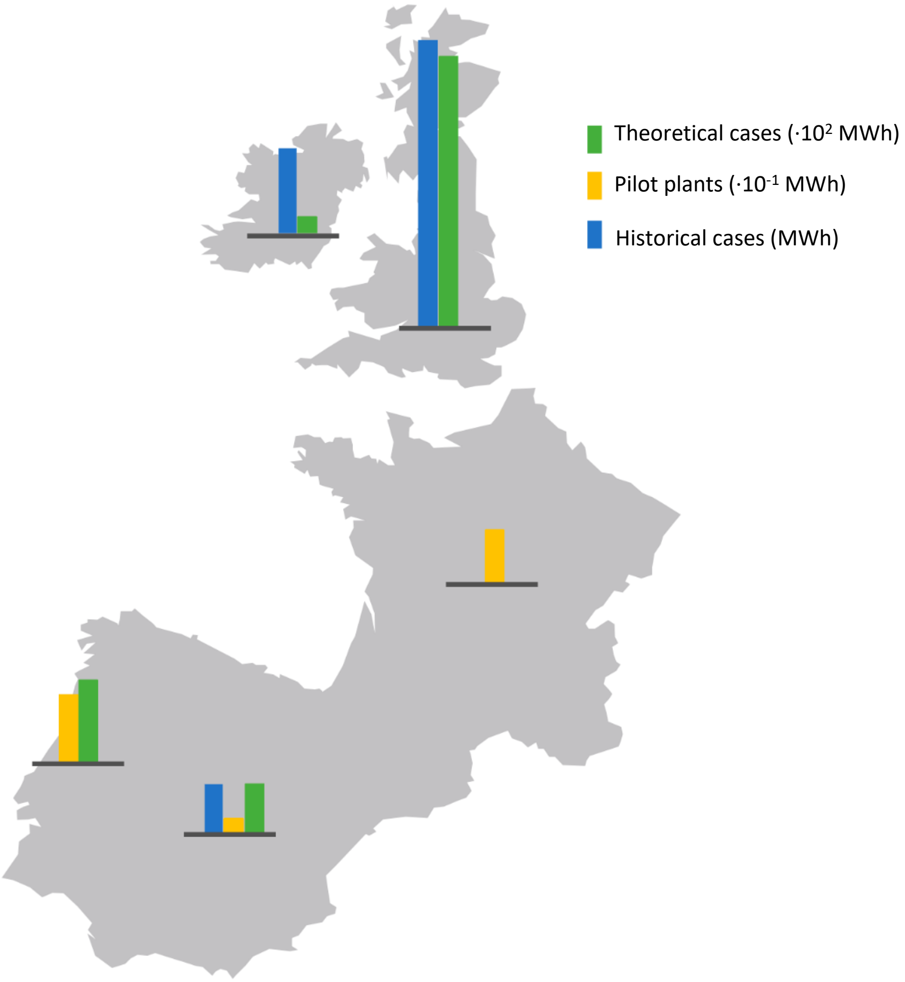
Table 1 summarises the set of business cases analysed, related to the historical cases, the pilot plants and the theoretical examples examined, for each of the sectors, as well as their size and location within the European AA, while the corresponding energy potential generation by category is displayed in Fig. 1.

Table 1. Business cases analysed for energy recovery through MHP in the Euroepan AA.

	Sector	Country	Size (kW)
Historical cases	Drinking water	Ireland	78
	Wastewater	UK	180
	Irrigation	Spain	32
	Industry	-	-
Pilot Plants	Drinking water	France	6.1
	Wastewater	-	-
	Irrigation	Spain	4
	Industry	Portugal	1.5 + 6.1
Theoretical cases*	Drinking water	Ireland, Portugal, Spain and UK	17945
	Wastewater	Ireland and Spain	1201
	Industry	Portugal, Ireland and Spain	1625
	Irrigation	Portugal and Spain	2995

* Based on data from 2626 sites collected during the REDAWN project, and suitable for installation of MHP (>2kW of power potential).

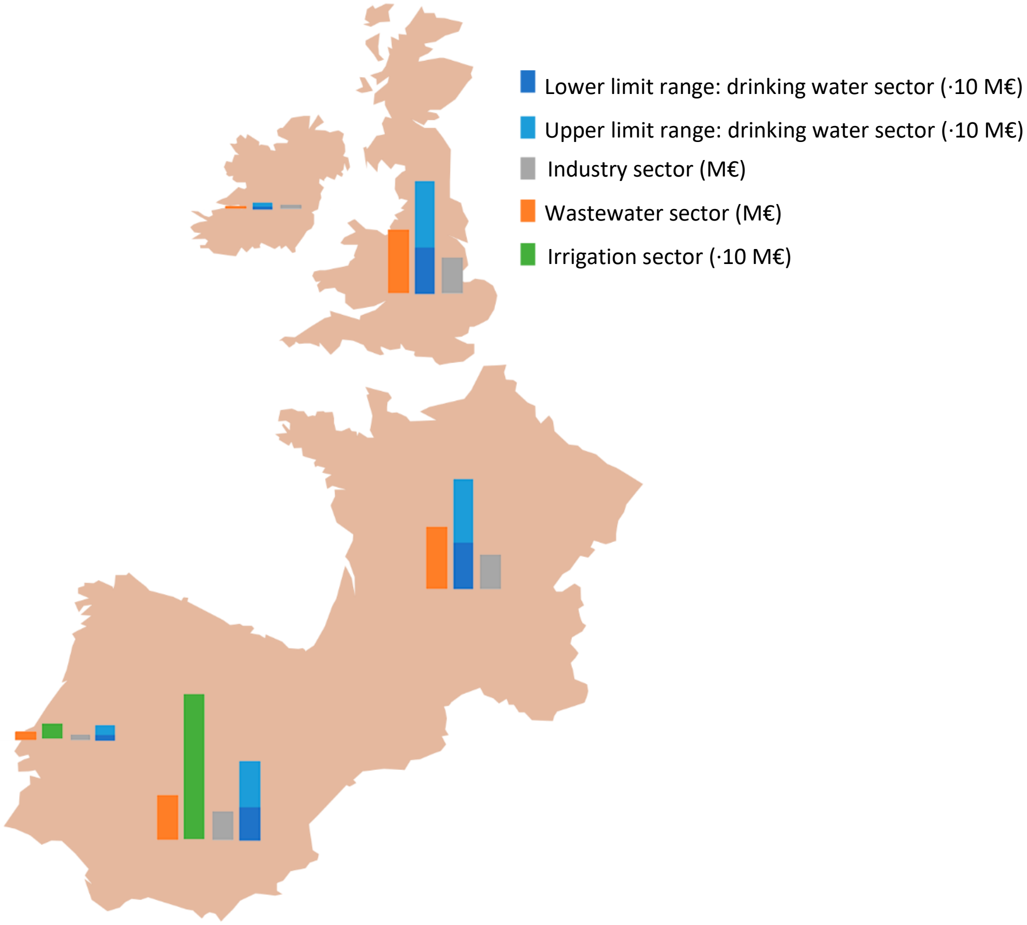
The analysis of all cases listed above, showed a total energy recovery potential with MHP (Fig. 1) of 2,3 GWh, 50.13 MWh and 188.1 GWh per year for the historical cases, pilot plants and theoretical cases analysed, respectively. This was determined considering a 24 h and 365 days a year as the operating time for all sectors, excluding the irrigation sector. The operation pattern of the real irrigation networks examined was considered to simulate the seasonality in the operation of the irrigation sector. This energy recovery potential would represent a potential saving of 559.14, 16.82 and 46.8 $\cdot 10^3$ tonnes CO_2 eq., and € 164920, € 10878 and M€ 40.8, for the historical cases, pilot plants and theoretical cases, in economic and environmental terms, respectively.



	France	*Ireland*	*Portugal*	*Spain*	*UK*
Historical case	0	480	0	280	1576
Pilot plant	29.43	0	35.6	8.7	0
Theoretical cases	0	9624	462	27799	150215

Figure 1. Energy generation potential results (in MWh) for the historical, theoretical and pilot plants analysed under REDAWN project for the different countries.

The analysis of the potential market (Fig. 2) was conducted based on the extrapolation of the energy recovery resources at a country scale, shown to be a total of between M€ 457.6 and M€ 707.9 for the four sectors (drinking water, wastewater, irrigation and industry sectors) and the set of countries (France, Ireland, Portugal, Spain and UK). These figures would be even higher if the internal water distribution networks of the water-intensive industries, for example, could be analysed. Current results for industry and wastewater sector were based on the discharge water volumes, and not taking advantage of the existent excess pressure, as it has been for the drinking water and irrigation sector, with a considerably higher potential.



	France	*Ireland*	*Portugal*	*Spain*	*UK*
Drinking water	64.4-152.4	4.7-11.1	10.1-24.0	46.5-110.0	65.5-155.0
Wastewater	8.7	0.6	1.4	6.2	8.8
Irrigation	0.0	0.0	22.0	202.7	0.0
Industry	4.9	0.8	0.9	4.2	5.2

Figure 2. Potential market in M€ for MHP in the different sectors and countries included in REDAWN.

In short, this report provides evidence that there is a great potential for activity around the integration of MHP technology in the water industry. This would allow for the reduction of grid electricity consumption or the use of fosil fuels, in public and private facilities, with the corresponding reduction in the cost of energy, even offering in some cases a complementary economic income, when excess energy can be sold. This reduction in the energy demand translates into a reduction of GHG emissions, contributing to the decarbonisation of the sector. In parallel, the interest in MHP technology will generate increased demand for turbines and PATs, which in turn will lead to an increased activity for companies involved in the commercialisation of the MHP technology and services.

2. Introduction

Climate change remains a serious challenge for the water sector. Water services work to minimise their impact and enact mitigation and adaptation measures, while controlling costs and complying with legislation. It is essential that water service providers develop long-term plans at this regard. Obviously, the water utilities are a source of greenhouse gas (GHG) emissions, so the optimization and reduction of energy use in the water industry sector would significantly reduce its carbon footprint. In this regard, saving energy and producing renewable energy are two key aspects to try to improve the efficiency of the sector.

REDAWN presents MHP technology as an opportunity for reducing overpressures, and thus, leakages in water networks, and producing green energy, thereby reducing the operation costs of water distribution networks, with consequent economic and environmental benefits. This provides new opportunities and benefits for society, and beyond that, for both the network managers and companies supplying MHP technology and services.

REDAWN focussed on the assessment of the opportunities for MHP technology in the drinking water, wastewater, process industry and irrigation sectors, with each one presenting its own particularities within the water industry.

Water supply and distribution, together with wastewater treatments, account for around 50% each of the total energy demand of the urban water sector in Europe, with an expected global increase in the use of electricity in the water sector exceeding 4% of the global electricity requirements by 2040 (Magagna et al., 2019). Undoubtedly, there is an important existing network of pipelines extended across the different European countries that provide both water supply and sewerage services. These networks represent, in the set of European countries included in REDAWN, between 5.29 and 15 m and between 4.03 and 19.1 m in network length per capita (Table 2), for the drinking water and wastewater sectors, respectively, with an annual average cost of water between € 91 and € 250 per capita, with France and UK as the countries with the highest average consumer prices.

Table 2. Water distribution and sewage network density by country in the European AA.

	Drinking water	Wastewater	Average residential consumption	Average price
	Network length per capita	Network length per capita	(l/cap/day)	(€/m^3)
France	15	6	170	4.03
Ireland	10.6	19.1	130	-
Spain	5.29	4.03	132	1.88
Portugal	11.3	7.2	204	1.82
United Kingdom	6.45	6.02	139	3.54

*Data compiled from (Eureau, 2020)

In these networks, numerous locations with excess pressure are usually controlled by the use of pressure reducing valves or break pressure tanks. This excess pressure in water distribution networks, or the available head at the discharge points of the wastewater treatment plants (WWTPs), could represent potential sites for energy recovery through MHP.

In a global context, the sector with the highest water consumption differs between countries. Nevertheless, in general terms, agriculture is the largest water consumer in southern Europe, while cooling in power generation represents the highest pressure on water resources in western and eastern Europe. The irrigation and process industry sectors are both traditional intensive water users, representing as global average around 70% and 20% of the global water consumption, respectively. In the case of Europe, the water consumption of agriculture, forestry and fishing activities reach around 58.3% of the total water use, while a 32.1% is due to energy, construction and service industries activities (EEA, 2017). In both cases, an increase in the total production, and therefore, an increase in the water and energy demand, is expected for the following years. In this context it is also worth noting that only 10-12% of water resources in Europe are associated with drinking water demand (EEA, 2018)

In 2016 the actual irrigated area was around 10.2 million hectares in the EU, from which Spain represented 30% of this total, followed by France, with 13% and Portugal, with 5% (Eurostat, 2019). The pressurisation of a large part of the water distribution networks, among other actions, as results of the modernisation of the irrigation sector in the last years, has significantly improved the efficiency of water use in agriculture, with the corresponding increase in the energy demand. As an example, the energy demand in irrigation accounted for an increase of more than 600% in the period 1950 to 2007 in Spain (Rodríguez Díaz et al., 2011), which combined with an increase in the electricity tariff, has had a direct impact on production costs for farmers.

This report includes a brief analysis of the energy, economic and environmental potential of MHP technology in the water sector and the benefits it could bring to public entities and private end-users, as well as to companies related with the development and commercialisation of this technology. The main structure of the report is organised in such a way that it presents some historical cases collected from different previous studies and reports, the pilot plants that have been developed under the REDAWN project, and a summary of the theoretical potential assessed in WP4, for the different sectors within the water industry in the European AA.

Each of the cases were studied from the energy production potential perspective, along with the estimation of the avoided CO_2 emissions and the potential or actual economic savings corresponding to each case. The energy recovery potential estimations were based on annual average information about flow and head pressure availability, in most of the cases, or real-time monitoring in the case of the pilot plants. In the case of the avoided CO_2 emissions, an average ratio of the greenhouse gas emissions intensity of electricity generation (as g CO_2 eq. emissions per kWh of electricity from the grid), for the countries included in the analysis, was used (EEA, 2020a). In this case, France represented the country with the lowest ratio, with 52 g CO_2 eq per kWh, and Portugal the highest, with 244 g CO_2 eq. per kWh, with an average of 209.4 g CO_2 eq. per kWh of electricity for the set of countries. Finally, the potential economic savings were determined based on average electricity prices for households for the European countries included in the analysis (Eurostat, 2020), among which Ireland was the country with the highest price, with €0.2413/kWh and France the cheapest, with €0.1899/kWh, resulting in an average electricity price of €0.217/kWh.

On the other hand, the potential market was estimated based on the extrapolation of the MHP potential results for the analysed sites in the different countries and sectors, based on the total population of the countries. Then an average total cost ratio per kW of nominal power for MHP plants was considered, based on small turbines or pumps as turbines, to determine the potential market in economic terms.

3. Business cases

3.1. Drinking water sector

The water sector accounts for around 5.5% of the total annual electricity consumed by households in Europe, although this figure varies substantially between regions (EurEau, 2019). Traditionally, pumping is the most energy intensive activity and represents around 80% of the energy use in the drinking water sector. The organisational structure of the European countries over the last 20 years has meant an important evolution in the management of water services from a predominantly public model, towards the emergence and development of the private sector, creating the opportunity for new management models. This is the case for the drinking water sector in Europe, for which the public, private or mixed nature of the service varies between countries, as shown in Figure 3.

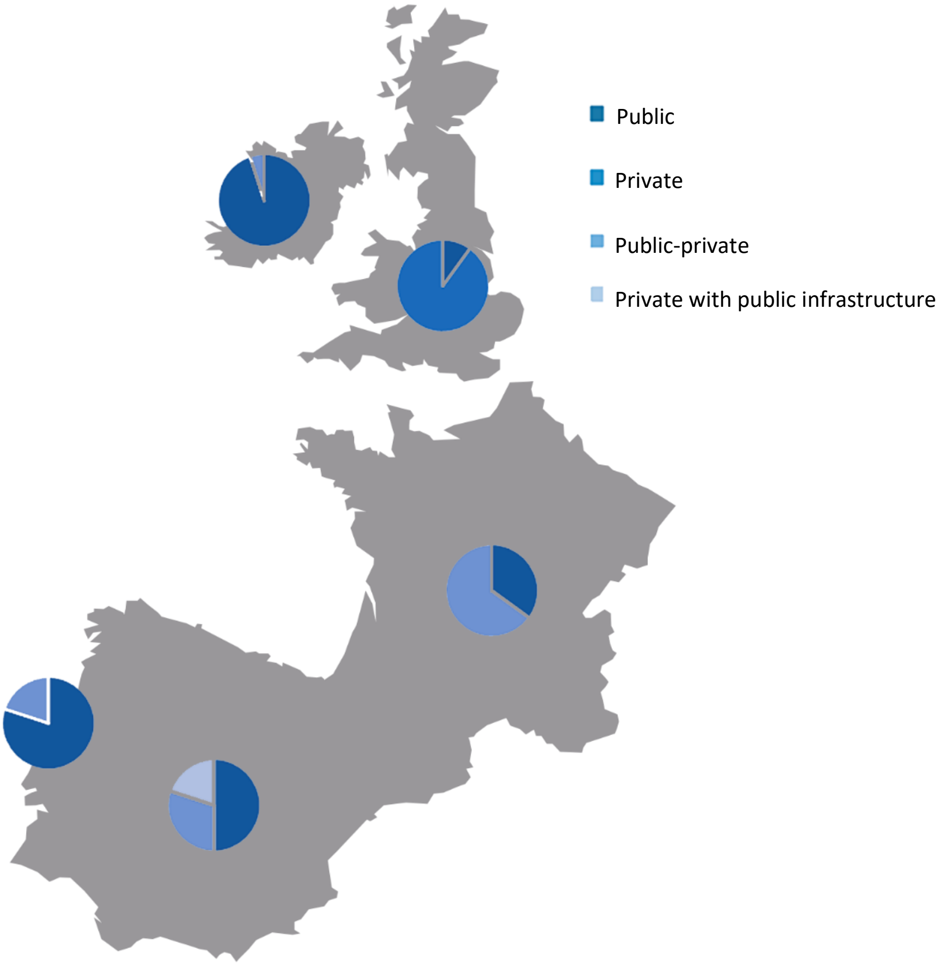


Figure 3. Management service for the drinking water sector by country.

*Data compiled from (EurEau, 2019).

Drinking water networks are complex pressurised systems which usually present excess pressure locations. This excess pressure is commonly dissipated by pressure reducing valves or break pressure tanks, to avoid pipe bursts and leakage. The installation of turbines or PATs allows the transformation of this excess pressure, which would otherwise be dissipated, into useful energy. The energy generated could be used on-site, reducing the total energy consumption of the installation, or injected into the grid, thus providing an extra revenue source.

In the following subsections, a historical case, a pilot plant and a summary of the theoretical cases for the drinking water sector are presented.

3.1.1. Historical case: MHP plant in Vartry Reservoir

The historical case for MHP detailed here for the drinking water sector has been gathered from a PhD thesis (2015) by Lucy Corcoran of Trinity College Dublin, entitled “Hydropower Energy Recovery from the Water Supply Network: Feasibility, Risk Analysis, Optimisation and Implementation”.

The MHP plant analysed in this case was placed at Vartry Reservoir Co. Wicklow, in Ireland (Fig. 4). This reservoir supplies 75 million litres of clean water per day, distributed partially in Dublin and Wicklow regions. The installation integrates two reservoirs. The main reservoir was completed in 1868, having added later an upper reservoir in the 1920s, which discharges to the original and lower one by a draw-off tower and valve house, after dissipating the excess energy.

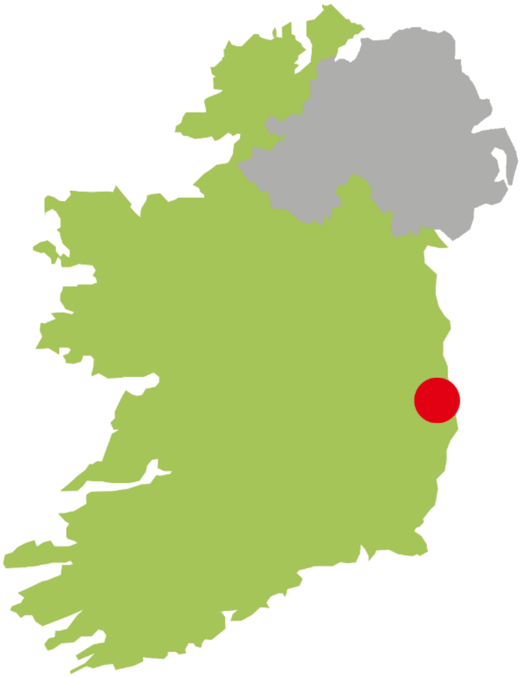


Figure 4. Location of Vartry Reservoir Co. Wicklow, in Ireland.

A 78 kW Kaplan turbine is operating and producing energy in this site since 2008. This hydropower turbine was installed in a by pass on the initial pipe network, between the valve-house and the stilling basin, downstream of the first of the reservoirs.

The turbine generates enough energy to power between 20-30 houses per year. This energy is enough to power the treatment works, with a significant amount of excess energy being sold to the grid. The monthly energy production of the turbine depends on the reservoir level, which varies through the year, achieving its lowest production in summer months. The annual average energy production is around 480000 kWh, representing a GHG emissions savings of 151.7 tonnes CO_2 eq. per year (Table 3). From the total energy generation, approximately 1/3 is exported to the grid. In this specific case, the cost of the energy from the grid reaches an average value of €0.14/kWh, and each kWh injected into the grid is paid at a price of €0.08. These prices, together with the energy percentage that is consumed on site and the remainder that is fed into the grid, would give an average annual economic saving of around € 57600 (Table 3), with an amortisation period of around 8 years, for an initial investment cost around € 490000.

Table 3. Energy generated, on-site consumed and sold, and the corresponding economic and environmental savings.

	kWh	€	Tonnes CO_2* eq.
Total energy generated	480000	67200⁺	151.7
Energy consumed	320000	44800	101.1
Energy inyected into the grid	160000	12800	50.6

*Considering an average ratio of CO_2 emissions for the grid electricity in Ireland of 316 g CO_2 eq per kWh
⁺Considering all energy generated consumed in the site

As shown in Table 3, the energy recovery potential estimated represented an annual saving, in environmental terms, of 151.7 tonnes CO_2 eq., considering an average ratio of 316 g CO_2 eq. per KWh of energy.

This historical case study illustrates the viability of MHP installations in drinking water networks, in the transmission section of the network where flow rates are higher and more steady, and the power outputs are on the larger scale of MHP. This allows the use of conventional hydropower equipment such as a Kaplan turbine in this case, with good return on investment achieved.

The challenge remains to capitalise on the many opportunities exist within the distribution section of the network where power outputs, and flow rates are smaller, and flow is also more varied. In the many locations of this nature in the AA region alternative hydropower equipment is required as demonstrated by the REDAWN project pilot plant activities.

3.1.2. Pilot plant: France

Introduction

The French pilot plant developed under the REDAWN project is placed at the SMPGA drinking water facility in Saint Pair sur Mer in Normandy (Fig. 5). In this case, a commercial pump is installed in the pressurised inlet pipe of the drinking water plant, working in reverse, to generate energy from the excess of pressure.

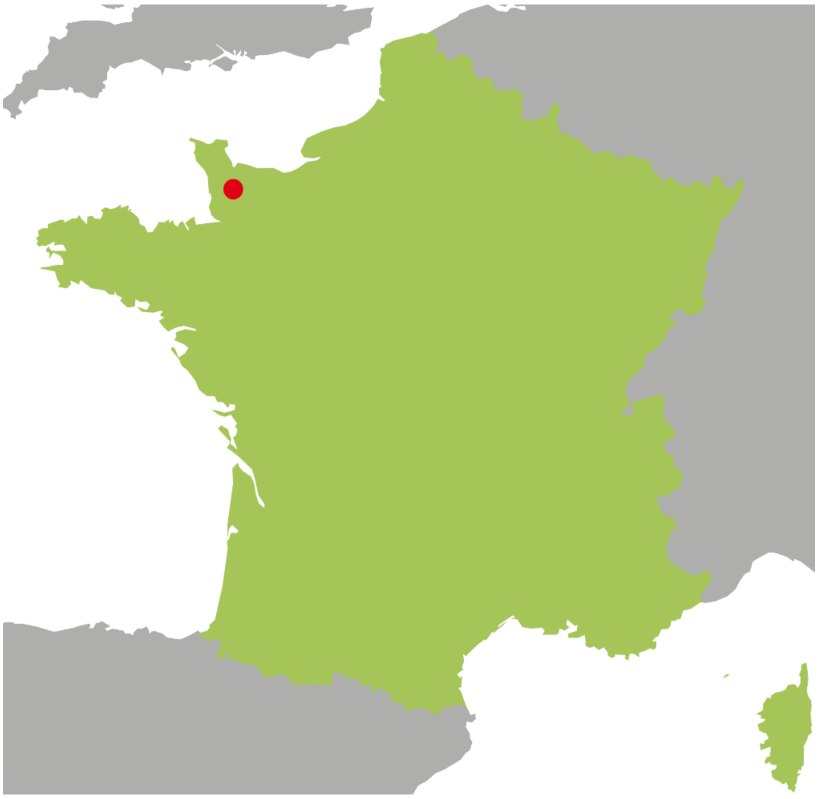


Figure 5. Location of the energy recovery pilot plant in France.

Pilot Plant Description

The PAT in the French pilot plant (Fig.6) takes advantage from a pressure drop of around 1 bar, in a pipe with an average flow of 340 m^3/h. The PAT has a nominal power of 7 kW, with a 268 V and 14.8 A generator.

The energy generated by the MHP plant is injected into the drinking water plant, reducing the total energy consumption of the treatment plant.

Figure 6. PAT installed on a bypass in the pilot plant in the drinking water sector in France.

Annual energy production

The energy generated by the PAT, with an average operating efficiency of 72%, is injected into the drinking water plant, where it is used. The PAT energy production represents around 4% of the total energy consumption of the drinking water plant.

Table 4. Energy production from the PAT and energy demand from the drinking water plant.

	Period	**Energy (kWh)**
Total energy consumed by the drinking water plant	2020	711211
Total energy generated by the PAT	2020	29433

Economic and environmental savings

The economic and environmental savings, for this pilot plant, were estimated based on the annual energy production potential and an average price and ratio for GHG emissions, for each kWh of electricity coming from the grid, in France. In this case, the average electricity price used was € 18.99 cents, and the average GHG emissions ratio per electricity unit consumed reached 52 g CO_2 eq. per kWh. Thus, considering the total energy production potential of the PAT, equal to 29.4 MWh, the economic savings would reach € 5589 per year, avoiding the annual emission of 1.53 tonnes of CO_2 eq. The annual savings, together with a total investment cost of around € 26050, allows to estimate a payback period of 4.7 years.

3.1.3. Theoretical cases in the drinking water sector

WP4 included a total of 7775 initial identified sites in the original database for the drinking water sector, to evaluate their potential for energy recovery with MHP. From this total, 2284 sites presented a MHP potential equal or higher than 2 kW, which was the minimum power threshold previously set, as smaller plants are usually considered not to be economically viable using PAT technology. A significant proportion of these sites with MHP potential were located in Scotland, which also accounted for most of the initial sites of the database for the drinking water sector (70%), where in most cases, data about flow and pressure were estimated and not recorded. The database for the rest of the countries included a substantially smaller volume of potential sites, or even no sites, as it was the case of England, due to the lack of available information.

The analysis of the database resulted in a total power potential of 17945 kW, which represented a theoretical annual energy recovery potential of 157 GWh, under a 24 h and 365 days a year operation regime. From this total, the 43% of the energy could be recovered in installations with nominal power over 15 kW. In a country-by-country analysis of the available data, the UK represented around 95% of the total theoretical potential for MHP, followed by Ireland (4%), Spain (<1%) and Portugal (<1%).

The annual energy recovery potential estimated represented a greenhouse gas emission reduction potential of around $39.1 \cdot 10^3$ tonnes CO_2 eq., considering an average conversion factor of 248.75 g CO_2 eq. per kWh for the electricity grid. In economic terms, the corresponding savings would reach M€ 35.2 annually.

It is worth noting that the above energy savings, and CO_2 savings are based only on the data collected in WP4 and does not include the full potential from all drinking water networks in the AA. This full potential was quantified in WP4 through extrapolation and is used in Section 4.4 of this report to estimate the size of the market for MHP exploitation as part of the buisness model for lead users of the technology.

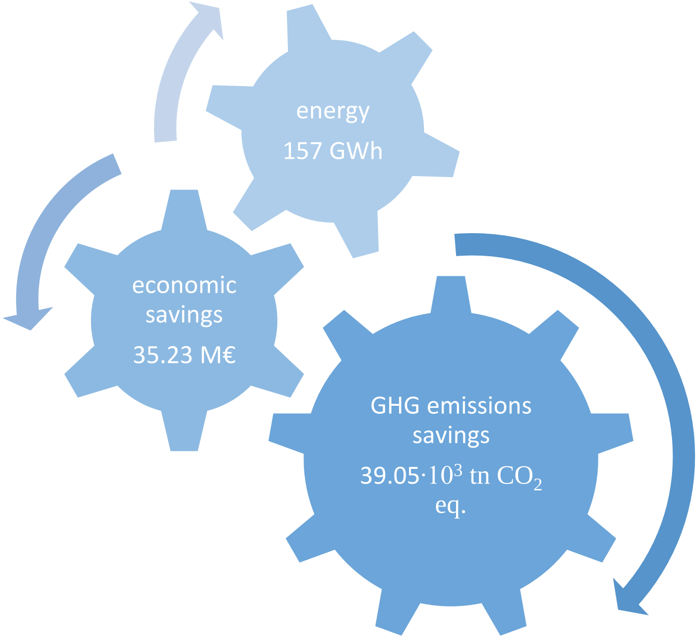


Figure 7. Summary of the energy recovery potential and the economic and environmental savings for the theoretical cases in the drinking water sector.

3.2. Waste-water sector

The energy demand from the wastewater sector accounts for more than 1% of the overall electricity consumption in Europe (EurEau, 2019). Usually, WWTPs use blowers to provide enough oxygen in sludge reactors, as an example. Other blowing systems, pumping, propellers and mixers account for most of the electricity demand. The potential for energy recovery in the wastewater sector mainly depends upon the discharge volumes, and the difference in height between the effluent generation point and the discharge point into the receiving waters. The effluent generation depends on the sewer system nature, with a predominance of the combined option in most of the European cases, in which a common network collects wastewater and rainfall water.

As previously outlined in the drinking water sector, the wastewater sector is managed by private, public or mixed organisations, depending on the country, as shown in Fig. 8, with a predominance of the public management option, which represents on average 49% of the cases.

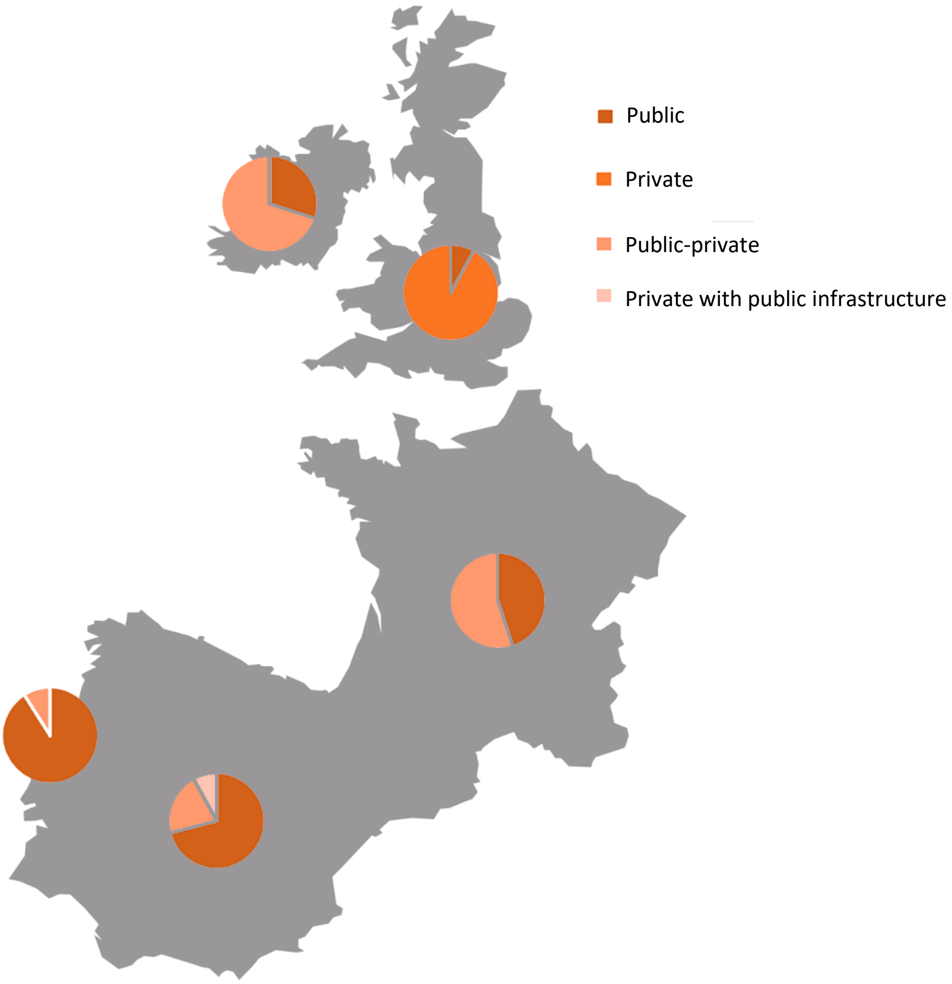


Figure 8. Management service for the wastewater sector by country.

There was no pilot plant for the wastewater sector developed under REDAWN project. For this reason, in this case, only an historical case and the summary of the theoretical cases were detailed below.

3.2.1. Historical case

The historical MHP plant selected for the wastewater sector is placed in Esholt (Fig. 9), in West Yorshire, England.

The installation of this MHP plant in a WWTP of Yorkshire Water company was completed in 2009, with the aim of producing green electricity from the inlet flows in Esholt after the initial screening phase.

Figure 9. Location of Esholt, in UK.

The MHP plant is composed of two Archimedes screw generators installed in series (Fig. 10), with 2.6 m of diameter, 14 m in length and 32 tons, each. The average flow is around 2.7 m^3/s, fed from the inlet works (using untreated sewage) upstream of the generators through a bypass chamber with a total head drop of 10 m. The installed power is equal to 180 kW (90kW per screw), producing energy in a 24/7 regime, which is fed into the main grid. Each screw turbine is connected to a 110 kW standard AC induction motor and an industrial drive used in a generator mode.

The energy generated, with an aproximated efficiency of 68%, is used to reduce the imported power demand of the WWTP, saving around € 400 per day in electricity costs, which represents nearly € 150000 a year.

Figure 10. MHP installed in a WWTP in Esholt, in UK.

Based on annual energy production, which is around 1576 MWh, and using an average ratio of 228 g CO_2 eq. per kWh of energy for UK, the energy recovery potential of the Esholt MHP plant estimated would represent an environmental saving of 359.5 tonnes CO_2 eq. per year.

This case study shows how even in WWTP, where no excess pressure in a pressurized pipe network is available, but only the head drop is used, it is possible to recover enough energy to partially or even completely supply the energy demand of the treatment work, representing important economic and environmental savings.

3.2.2. Theoretical cases in the wastewater sector

In the case of the wastewater sector, the MHP potential estimated for the study area was based on the available head pressure, due to the difference in height between the flow emission point and the discharge point into the river, and the average flow, estimated from the annual discharge licenses of the different WWTPs.

The collected database analysed under WP4 included a total of 878 identified sites for the wastewater sector. In this case, those sites were located in Ireland (61%) and Spain (39%), having no information for this sector for the rest of the countries.

The results showed a total theoretical power potential at the existing sites in the wastewater sector of 1201 kW, which represented an annual energy recovery potential of 10.5 GWh. In the case of the wastewater sector, the number of sites with exploitable potential was lower than in the case of the drinking water sector, as in many cases, the required head pressure was not available.

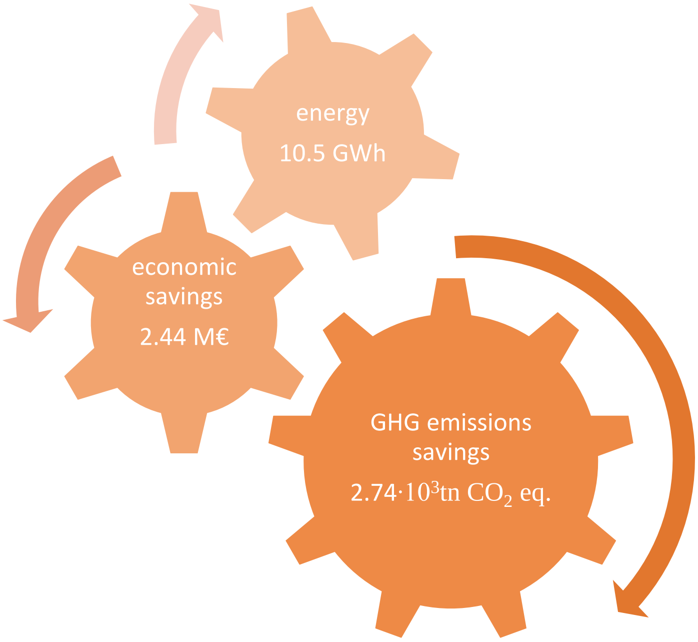


Figure 11. Summary of the energy recovery potential and the economic and environmental savings for the theoretical cases in the wastewater sector.

The total energy recovery potential represented a potential economic annual saving of M€ 2.44, considering an average unit cost of electricity of € 23.26 cents per kWh of electricity, for Ireland and Spain, avoiding the emission of $2.74 \cdot 10^3$ tonnes CO_2 eq. each year.

3.3. Irrigation

Agricultural activity is particularly intensive in terms of water demand, especially for irrigation, which plays a crucial role in food production. This water demand is linked to an important energy consumption, which is normally supplied by the electricity grid, in on-grid farms, and by diesel generators in those isolated from the grid.

Around 7-8% of the total agricultural area in Europe is irrigated, and this figure reaches 15% in Sothern European countries (EEA, 2019). Irrigation has the particularity of being a seasonal activity, with the highest intensity in the periods April-August. For this reason, the energy generation potential, for the same nominal installed power, is always lower than that which would be generated in the case of the drinking water sector, for example, under a 24 h 365 days a year operation pattern.

3.3.1. Historical case: MHP plant in Novelda.

The historical case related to the irrigation sector is located in Alicante (Southeast Spain) (Fig. 12). The MHP plant is installed in the irrigation district of Sociedad del Canal de la Huerta de Alicante. This irrigation district is supplied by the water coming from Villena, which in turn is fed by an aquifer with the water level at 200 m below the ground.

Figure 12. Location of the energy recovery plant in the irrigation sector in Novelda (Spain).

The hydropower plant is specifically located in Novelda, taking advantage of the difference in altitude compared to Villena, due to the hilly nature of the area. Therefore, pressure reducing valves are often installed to control the overpressure generated by the topographic conditions. In 1989, a 250 kW Francis turbine was installed in a MHP plant in "Los Navarros". This plant was designed to operate with a 40 m difference in height and a flow rate of 300 l/s. Nevertheless, fluctuations in the design flow rate make the plant efficiency low. For that reason, a new turbine was installed in a by-pass, in addition to the original one. This new turbine was designed for a 120 l/s flow, and 35 m of head pressure, with a nominal power of 32 kW, including a variable speed drive.

In general, this new turbine is working during 10 months of the year, as the flow in these months is not enough for the original Francis turbine, which works during the two peak months of the year, matching with the summer period. The annual average energy production of the new turbine is around 280 MWh. Therefore, with the addition of the new turbine, the MHP plant has been modified to be able to work in a wider range of flow conditions.

In this case, the energy generated by the MHP plant is sold to the grid, at a rate of € 0.05 per kWh. The cost of the installation of the new turbine, including the engineering, equipment and civil works was around € 53.000, with a payback period of 8 years.

The potential annual energy generation represented for this installation an annual economic saving of € 62692, avoiding the emission of 57.96 tonnes CO_2 eq. per year.

3.3.2. Pilot plant: Southern Spain

Introduction

The Spanish MHP Pilot Plant, developed under REDAWN project, is located in the irrigation network of an off-grid farm of around 170 hectares of walnut trees, within the left Bank of the Genil River Irrigation District, in Southern Spain (Fig. 13). This hydraulic installation is a pressurized and branched irrigation network, which operates with a minimum service pressure at hydrant level of 35 m. The irrigation network of the farm was supplied by a single hydrant, fed from a centralised source at irrigation district level. Nevertheless, the farm was originally equipped with a 6 kVA diesel generator, to supply the energy demands from an automatic fertigation system, together with other complementary loads.

Figure 13. Location of the pilot plant in the irrigation sector in Southern Spain.

The objective of the Spanish MHP Pilot Plant was to replace the diesel generator with a hybrid renewable energy installation composed of a pump, working in reverse as turbine (PAT), two PV panels and a battery bank, to supply the seasonal energy demand at farm level. The energy demands come from two fertigation pumps, 78 electro-valves for the filtering system, and an air compressor for maintenance operations, with a maximum power requirements of 3.6 kW.

Pilot Plant Description

The PAT, with a nominal power of 4 kW was installed on a by-pass of the water intake system that feeds the irrigation network of the farm, working with the head pressure of the incoming water. An extension of the valve house on the farm (Fig. 14) allows to host the different elements that make up the pilot plant (Table 3), with two solar PV panels installed on the roof, with a total nominal power of 660 W.

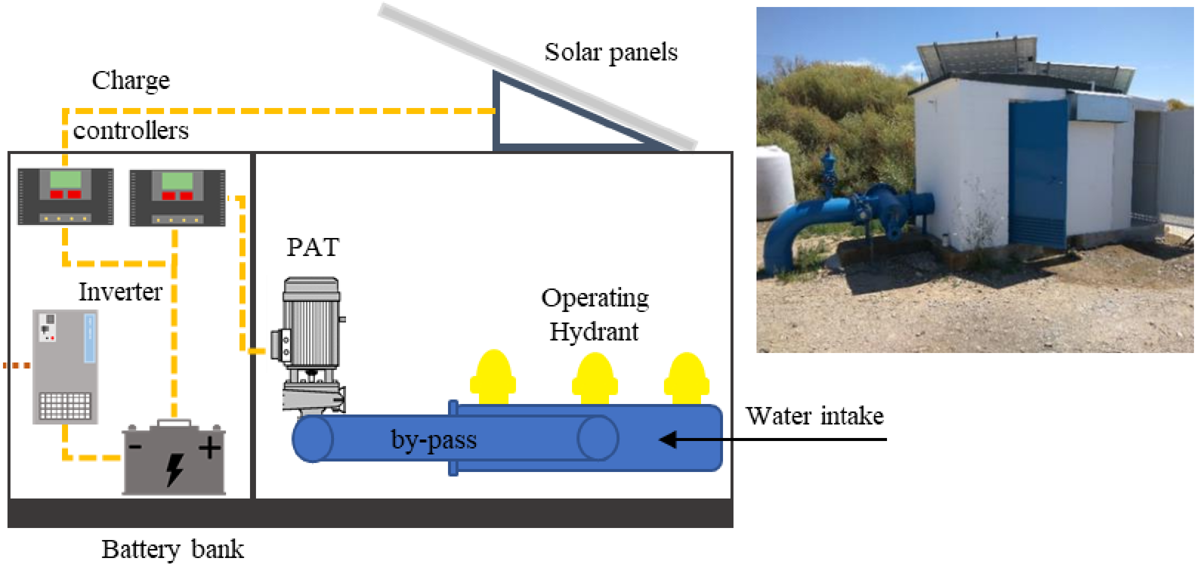


Figure 14. Schematic and outdoor view of the energy recovery Pilot Plant in Spain.

Table 5. Main components of the hybrid PAT-PV system and their principal characteristics.

Component	Model	Description
Turbine-generator	INLINE 080-B	4 kW, 20 m pressure head and 30 $l \cdot s^{-1}$ flow rate
Cut-off valves and pipe	-	Cast iron
Charge controller	MPPT (Schneider-electric)	Capacity of up to 80 amps
Panel with rectifier and solar charge controller	PWM 48-20 (Victron)	-
Battery bank	AGM monobloc	Total capacity 10.56 kW. Self-discharge rate 2% per month (20ºC)
Three phase inverter panel	3 Victron single-phase inverters (model 48/3000)	18 kW peak power
Solar panels	AMERISOLAR	2x330 W. Polycrystalline (1956x992x40 mm).
Extension of the house	-	Sandwich panels, metallic frames, door, and reinforced concrete.

The installation is monitored through a system of remote sensors recording the energy production of the system and a set of hydraulics and electrical parameters.

Annual energy production

The annual energy production of the pilot plant depends on the energy output from the PAT and PV panels. The PAT operation time is subject to the operating hours of the water distribution network in which it is installed. Due to that, the seasonality of irrigation, and thus, the operating time of this pilot plant, is one of the particularities to be highlighted, since the irrigation network is not working all year. When the irrigation network is not operating, the solar PV panels supplements the batteries to ensure they remain fully charged.

The annual energy production of the Pilot Plant for one representative irrigation season (2019), with an average irrigation time of around 3199 h per year, is detailed in Table 6.

Table 6. Energy production and maximum energy potential production in the Spanish pilot plant.

	Period	Energy (kWh)
Current power input to the batteries by the PAT	1 irrigation season	429
PAT potential energy generation	1 irrigation season	8701
Current power to the batteries by the PV panels	1 irrigation season	118
PV potential energy generation	1 year	1236
Current energy demand	1 irrigation season	222

As shown, the potential energy production of the pilot plant is significantly higher than the current production, since the operating time of the PAT and solar PV panels is restricted, and even lower than the total number of irrigation hours, as the energy demand at the farm is low. The energy used only represents 5% and 10% of the total potential production for the PAT and solar PV panels, respectively. The total potential production of the pilot plant was estimated based on the total operation hours of the irrigation network, for the PAT, and the irradiance levels for the entire year, for the solar PV panels. As an off-grid installation, the surplus of energy that is not consumed cannot be fed into the grid and sold to date.

Economic and environmental savings

The economic savings associated with this pilot plant are mainly related with the non-consumption of the fuel to power the diesel generator during the irrigation season. This same fact results in environmental savings, as no GHGs are emitted.

The total cost of the Pilot Plant corresponded to the equipment acquisition, installation and construction of the extension of the valve house, with virtually no maintenance costs. However, the diesel generator that it replaces implied the annual cost of the fuel consumed throughout the irrigation season. Considering an average price of € 0.69 per liter for the diesel for agricultural equipment in Spain, and the annual diesel consumption in the farm, the payback period of this plant would be slightly below 9 years. After the amortisation of the investment, the annual savings from the farm operation with the pilot plant would be around € 2500.

In environmental terms, and assuming an average greenhouse gas emission of 0.088 kg CO_2 eq per MJ, the replacement of the diesel consumption by the use of the green energy generated by the pilot plant avoid the emission of 12.36 tonnes CO_2 eq. per season. Of course, if all the energy that can potentially be generated by the pilot plant were consumed, the economic and environmental savings would be much higher.

3.3.3. Theoretical cases in the irrigation sector

The data collection in the irrigation sector, compared with the rest of sectors, was more difficult, as in many cases, the flow and pressure parameters are not recorded. The theoretical cases for the irrigation sector included the analysis of 18 different irrigation networks in Spain and Portugal, which were modeled and analysed, covering a total area of 36536 ha. In this case the total power potential estimated for the 18 irrigation networks amounted to 2994.6 MW, with an annual energy recovery potential of 6.11 GWh. In the case of the irrigation sector it is important to note that the installations operate seasonally, with most of the energy generation concentrated in the summer months (from June to September), matching with the most common irrigation season in the european southern countries. This energy generation potential represented an economic savings of around M€ 1.33 per year, considering an average price for electricity in Portugal and Spain of € 21.8 cents per kWh. In environmental terms, and again considering an average ratio for the GHG emissions linked to the production of 1 kWh of energy in these two countries, the energy recovery potential would avoid the emission of $1.38 \cdot 10^3$ tonnes CO_2 eq per year.

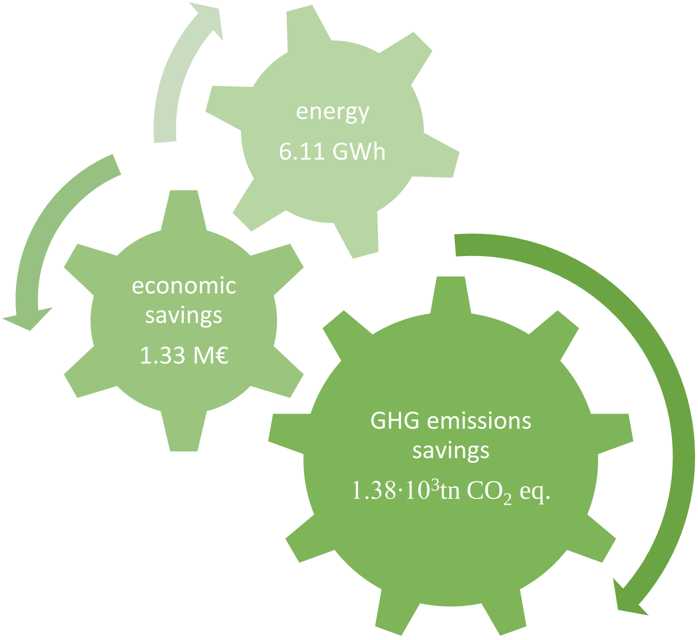


Figure 15. Summary of the energy recovery potential and the economic and environmental savings for the theoretical cases in the irrigation sector.

3.4. Industry

The industry sector has traditionaly been energy and water-intensive, with a strong impact of the activity nature of each particular industry. The industry sector energy consumption accounts for around one-quarter of the European final energy consumtpion. Recent studies assessing the european energy trends concluded that final energy consumption is primarly influenced by an increase in energy efficiency in industry, followed by household (Thomas and Rosenow, 2020).

Sectors, such as indusrty, with a large consumption of electricity, are also major water users, putting pressure on water resources both directly and indirectly. As an example, in 2017 cooling in energy generation used around 18% of the total water consumed in Europe, making this activity the second highest consumer of water after the agriculture sector (EEA, 2019). The high energy demand and the large volume of water consumed by this sector, suggest that MHP technology could have an interesting potential to reduce energy consumption and thus reduce the cost of its activity in economic and environmental terms. However, the hermetic nature of the private sector makes it difficult to collect information about their internal water distribution networks.

In this case, no historical case was found for the industry sector, and so the pilot plant and a summary of the theoretical cases analysed are descrived below.

3.4.1. Pilot plants: Portugal

Introduction

The pilot plant in the industry sector was located in two different sites in Portugal. One of them, already in operation, was placed in Seixoso (Fig. 16). In this case, the MHP plant takes advantage of the water resulting from the activity of a Tungsten mine, which is stored in a reservoir. The second pilot plant in Portugal is under construction. This MHP plant is located in Server do Vouga, in a agro-tourist centre, where tourism activity includes the agricultural production for food supply (service industry and irrigation sector). In this case, the water that powers the turbine comes from a river, in which there is a small weir. A fraction of the turbined water feeds the water demand of the agricultural activity in the centre, with the rest used to maintain the ecological flow of the river.

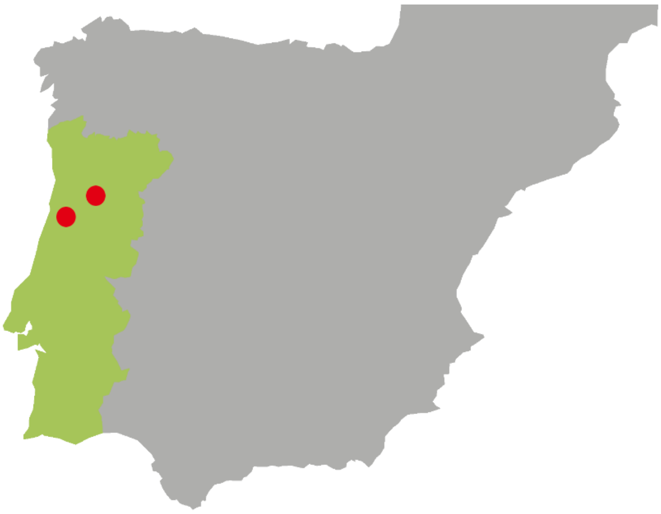


Figure 16. Location of the pilot plants in Portugal.

Pilot Plants Description

In the case of the MHP plant in Seixoso, an adapted pico Pelton turbine was coupled to a 1.5 kW generator. The estimated head pressure at the turbine location was around 55 m, with an average measured flow of 5 l/s. The head pressure resulted from the difference in height between the inlet (reservoir of the Tungsten mine) and outlet (MHP plant), 350 m apart. The energy generated is then rectified by a solar inverter placed 350 m away from the powerhouse, and is finally used to supply the energy demands from a family home of four inhabitants, specially to charge an electric car, as well as other typical electric devices in the house.

Figure 17. Pilot plant in the mine reservoir in Portugal.

The MHP plant under construction in Server do Vouga (Fig. 18) was designed to partially supply the energy demands of the agro-tourism centre, with an annual energy demand of 35.4 MWh. The turbine of the MHP plant (6.1 kW on the turbine shaft and 5.3 kW at the generator output terminals), connected to the weir by a 178 m long pipe, will operate with 7.7 m head pressure and a 120 l/s flow rate, with this installation prepared to house a second turbine in the future.

Figure 18. Pilot plant in the agro-tourism centre in Portugal.

Annual energy production

The potential energy production estimation of the pilot plant in Seixoso is around 1000 kWh per month, which results in an annual energy generation potential of 12 MWh. However, the energy production recorded for the last three years for the MHP plant was lower, with 3.9 MWh, 2 MWh and 5.9 MWh for 2018, 2019 and 2020, respectively. The total energy demand from the family home is around 8-9 MWh per year, so the energy recovered through the MHP plant represented between 22% and 74%, for the set of years analysed. The total energy production of the MHP plant is restricted as the house is also provided with solar energy, and does not need to produce more energy, as overall, the generation capacity far exceeds the total energy demand.

The MHP plant in Server do Vouga is estimated to generate around 23600 kWh annualy. From this total, 60% of the potential generated energy will be partially used to cover the energy demands from the agro-tourism centre, reducing the energy consumption from the grid in a 40%. The remaining energy generated, will be used for domestic hot water in the centre.

Economic and environmental savings

The energy production estimations in the MHP plant in Seixoso would represent an economic saving of € 200 per month, with a sellback ratio of 0.2, resulting in an energy generation value of 2400 €, which allows to cover the investment costs with a payback period of approximately 4 years. In environmental terms, and considering an average ratio of 244 g CO_2 eq. per kWh of electricity consumed, the estimated energy potential generation would avoid the annual emission of 2.93 tonnes CO_2 eq.

The energy production estimations in the MHP plant in Server do Vouga would represent an economic saving of more than 40% of the current electricity bill in the centre. Considering the total energy capacity production, and an average ratio of 244 g CO_2 eq. per kWh of electricity, in environmental terms this plant will avoid the emisission of 5.76 tonnes CO_2 eq.

3.4.2. Theoretical cases in the industry sector

The data collection in the private industry sector was challenging, as in many cases, private industries are reticent to share the required information, and this information is spread across the many thousands of water-intensive companies. The theoretical cases for the industry sector collected for the energy recovery potential assessment in WP4 included 23 potential sites in 4 private industries in Ireland (3 industries, 22 sites) and Portugal (1 industry, 1 site), and the discharge licenses corresponding to the industries located in 7 river basins in Spain (Duero, Ebro, Tajo, Jucar, Guadiana, Guadalquivir and Segura), covering 78% of the total country area. The analysis of the specific sites in the private industries in Ireland and Portugal, showed a MHP potential of 211.6 kW and 10 kW, respectively. However, in the case of Spain, the information related to the annual discharge volumes reflected in the discharge authorizations allowed for the estimation of the average flow, considering 24 h and 365 days a year as operation time. These average flows together with the difference in height between the industry and the discharge point into the receiving water, allowed the estimation of an energy generation potential of 1402.9 kW. In the case of Spain, a total of 87 industries in which a hydraulic head less than 15 m was required for a 2 kW MHP plant, were analysed. 38 of them presented an MHP potential above 2 kW of power, with a total power potential of 1.4 MW and an average annual energy recovery potential estimated of 12.3 GWh. In this case, the private industries were grouped based on their principal activity, so the assessment also showed that the energy-related industries represented the greatest contribution, with 89% of the total power potential estimated.

Considering all sets of sites analysed, the energy recovery potential would reach a total of 14.23 GWh, which would represent an annual economic saving of M€ 3.21, considering the average price ratio per kWh of electricity for the three countries, equal to € 22.57 cents. In environmental terms, this energy potential production would avoid the emission of $3.64 \cdot 10^3$ tonnes CO_2 eq. each year.

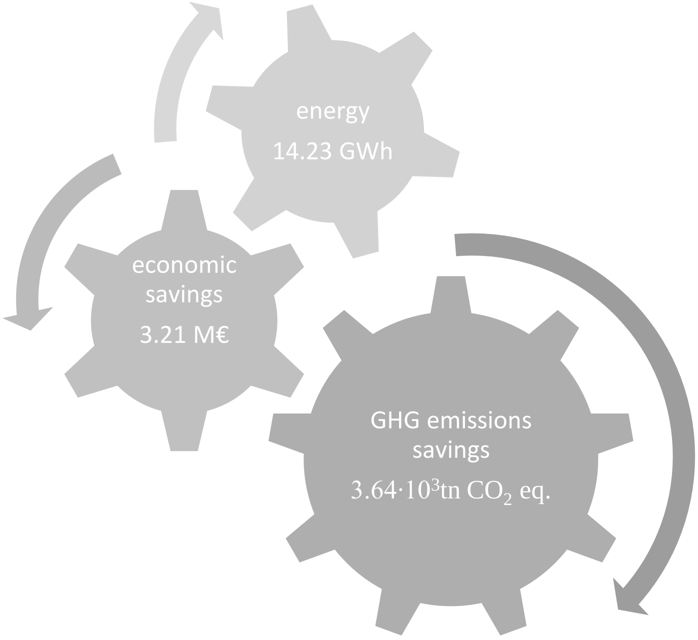


Figure 19. Summary of the energy recovery potential and the economic and environmental savings for the theoretical cases in the private industry sector.

3.5. Conclusions from the business cases

The results obtained from the different historical case studies, pilot plants and theoretical case analysis show that there is a significant exploitable potential for MHP technology that could reduce energy consumption from the grid, or from fossil fuels from energy recovery in water distribution networks in the drinking water, wastewater, private industry and irrigation sectors. The difficulty in data access was not uniform for all sectors, so it would be necessary to obtain more detailed information about internal distribution networks in water-intensvie industries and real time flow rates from wastewater plants, in order to be able to assess in more detail the exploitable potential in these cases.

In summary, the cases analysed show an optimistic scenario for energy recovery through MHP in the European AA, in which it would be possible to recover annualy more than 188 GWh, with relatively short and affordable amortisation periods, in the specific cases analysed. This energy production would not only reduce the total energy demand of the facilities in which the MHP plant is integrated, but would also bring economic and environmental benefits over the useful life of the MHP plant, rising global values around more than M€ 42 and 46000 tonnes of CO_2 eq., respectively, for the facilities analysed.

It is again worth noting that the above energy savings, and CO_2 savings are based solely on the data collected in WP4 and does not include the full potential from all water networks in the AA. This full potential was quantified in WP4 through extrapolation and is used in Section 4.4 of this report to estimate the size of the market for MHP exploitation as part of the buisness model for lead users of the technology.

4. Business model

4.1. Introduction

A business model is a tool that precedes the business plan, which allows the definition of the service or product to offer to the market, how to commercialise, the potential customers and how the income will be generated (Fig. 20). Obviously, the creation of a business model to initiate the commercial activity will require a more specific study of each case and approach, as well as the size of the company to be created. In addition, the service or activity here related is already known and defined, as the different activities and services around the implementation of MHP technology in the water industry sector. Therefore, in this case, the aim of this section will be to show, in a summarised way, the size of the potential market for this technology, from a technology/service provider perspective, within the MHP framework.

The main aspects organised under a generic business model are shown in Fig. 20. Those that we will try to discuss here are highlighted in green, focused on the potential market and the economic analysis of the commercial activity.

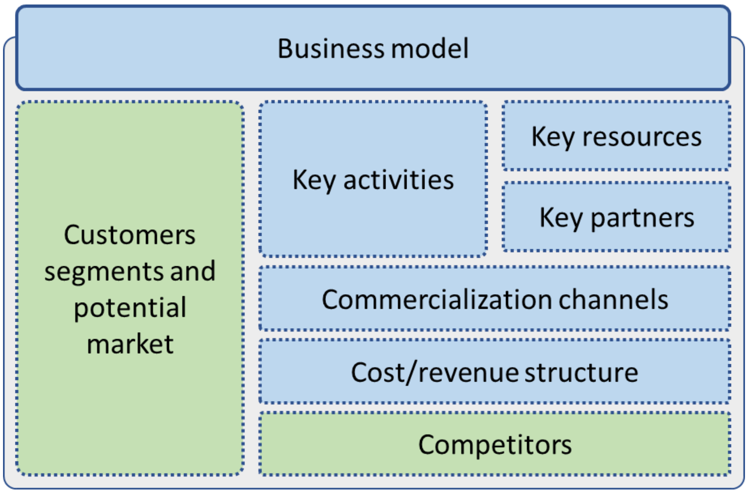


Figure 20. General structure and sections integrated in a the business model.

4.2. Context

The global energy demand is growing, with most countries relying on fossil fuels as the primary energy source. Even though in the European Union the energy production includes an increasing share of renewable sources, the energy related activities remain the largest GHGs emission contributor, representing around three quarters of the total. Hydropower is a mature and renewable energy technology which plays an important role in decarbonising the global energy system. In 2019, hydropower represented more than 1300 GW of global hydropower capacity installed (IEA, 2020), corresponding to 12.3% of the total electricity production in EU-27 (EEA, 2020b). This percentage varies between countries, with Portugal holding the highest percentage of hydropower installed capacity in a country-based analysis by energy sources, from the set of countries included in REDAWN. However, in absolute terms, Spain and France represent both the highest installed electricity capacity for hydropower, with more than 20 GW each. These figures are represented in Fig. 21, in which the total hydropower installed capacity is displayed in bars, together with the percentage that it represents in the total electricity generation capacity by the different sources, in pie charts, in each of the countries.

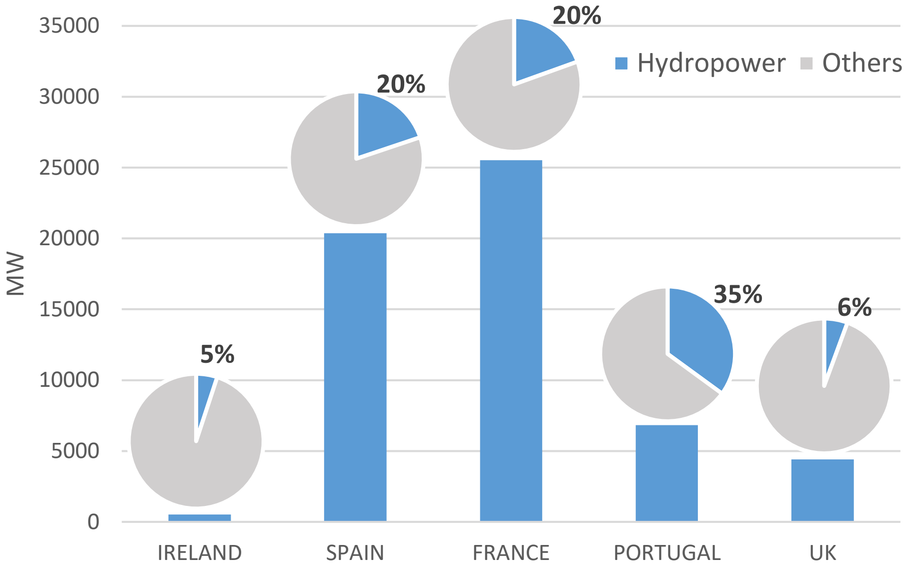


Figure 21. Hydropower installed capacity per country in MW and its percentaje contribution in the total installed electricity capacity per country.
*Data collected from (LIU et al., 2019)

Small hydro is a concept which refers to hydropower plants for small-scale projects for green energy production, usually below 10 MW of power. The small hydro group can be further subdivided into pico-hydro, up to 5 kW of power; micro-hydro, up to 100 kW; and mini hydro, between 100 kW and 10 MW, although these values may vary between countries. The smaller size of pico- and micro-hydro plants allows its integration in pre-existing facilities, where there is an excess head or pressure, which can become a potential MHP energy recovery plant. In this way, and in general terms, the environmental impact of small hydropower (SHP) plants, which are smaller in size and, as we have already mentioned, can be installed in pre-existing facilities, have a lower environmental impact than big projects involving the construction of large reservoirs, which usually generates some controversy.

The water industry is an energy intensive sector, from which the largest increase in energy demand in the last years comes from desalination, large-scale water transfer and wastewater treatment (Fig. 22). However, there is still potential for energy savings by energy efficiency and energy recovery strategies, actions that will help reduce the economic and environmental impact of energy consumption in this sector.

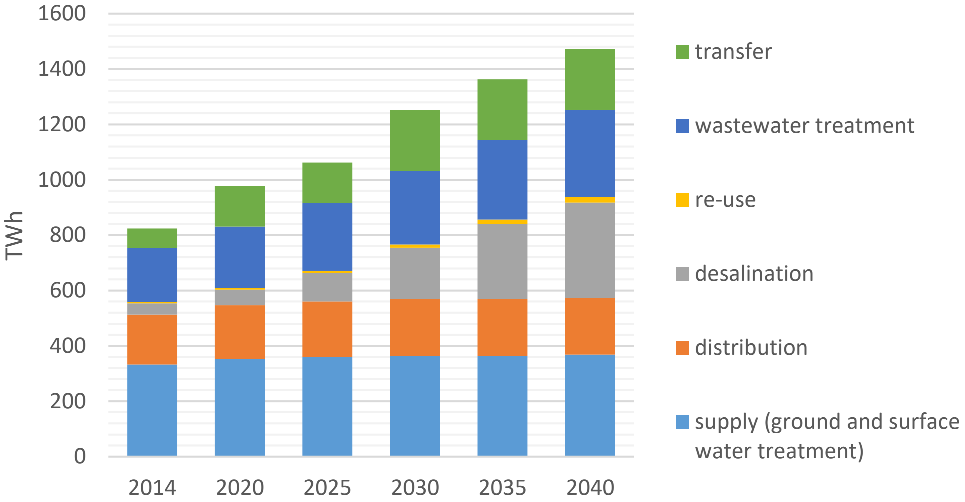


Figure 22. Electricity consumption in TWh in the water sector by process.

*Data collected from (IEA, 2020)

4.3. Potential market

Beyond the potential sites listed in the database compiled in WP4, also summarised in the theoretical cases in the "3. Business Cases" section of this document, this same WP4 has developed an estimation of the potential for energy recovery in the water industry sector at a country scale. Thus, based on the existing energy recovery potential estimated for the identified sites, and the population served by the corresponding analysed networks, WP4 developed a methodology for the extrapolation of the resources to a country scale, considering the total population of the different countries. The methodology was adapted to each sector, as detailed in the WP4 report.

Once the results of energy recovery potential were extrapolated, the potential market was estimated following the methodology proposed by (García et al., 2019). This methodology proposes the estimation of the total cost based on the PAT and generator costs, which together represent on average around 26% of the total MHP plant cost. Thus, the PAT and generator cost is calculated based on flow and head pressure data, following the equation:

$$C_{PAT+gen} = 12717.29 \cdot \ Q_{PATBEP} \cdot \sqrt{H_{PATBEP}} \cdot 1038.44 \qquad (1)$$

in which the $C_{PAT+gen}$ represents the cost of the PAT and the generator, in €, and Q_{PATBEP} and H_{PATBEP} the flow and the head pressure for the best efficient point of the PAT, respectively.

Based on the aformentioned methodology, this $C_{PAT+gen}$ represents as average, the 26% of the total cost of the MHP plant, based on nine installations analysed which used PATs as energy recovery technology. Therefore, to finally estimate the potential market based on the power potential, in kW, for each sector, the average flow and head pressure rates obtained for the different sites analysed for each of the sectors was determined. Then, with Eq. 1, an average cost per kW of nominal power was obtained for each sector, which together with the total power potential extrapolated defined the potential market in economic terms.

4.4.1. Drinking water sector

The potential for energy recovery through MHP extrapolated for the European AA, for the drinking water sector, was based on the population density of the different countries. The previous analysis of the initial identified sites showed clear differences between countries in their individual ratios of power potential to population served by the networks. In addition to that, some of the countries had no information, and in some cases, most of the data were estimated rather than measured. For this reason, the potential for energy recovery extrapolated to a country scale was then made under four different assumptions, considering the individual ratios, median and averages (total and a partial average) of the ratios. This methodology is explained in detail in WP4.

The extrapolation procedure finally showed a potential for energy recovery for the drinking water sector of between 558.1 and 1321.1 GWh per year. These figures correspond to an average power potential installed of 141 MW, considering the average MHP potential ratio of 0.73 kW per 1000 population, distributed between countries as shown in Fig. 23.

Following the described methodology (García et al., 2019) to estimate the total cost of the MHP installations based on PAT technology, with an average cost ratio for the drinking water sector of 2026 €/kW, the potential market would reach a total of M€ 285.8 in the set of countries analysed, considering the average ratio of 0.73 kW per 1000 people. This result would be in the range of M€ 129.1 to 305.7, which corresponds to the range of potential energy recovery under the different assumptions analysed in WP4 for the drinking water sector.

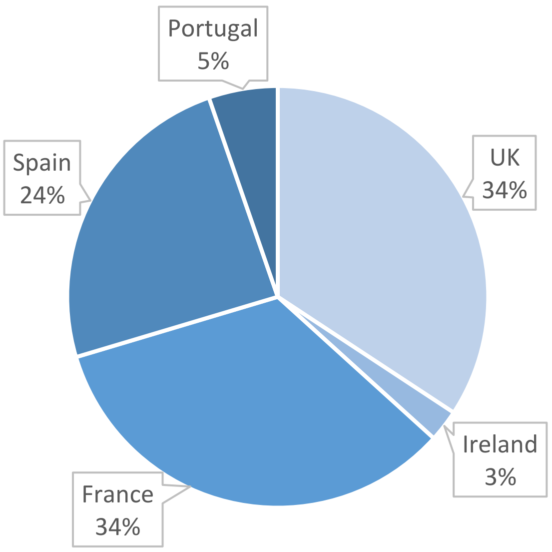


Figure 23. Percentage distribution between the different countries of the potential market for MHP in the drinking water sector.

4.4.2. Wastewater sector

In the case of the wastewater sector, the extrapolation of the MHP potential was based on the linear correlation found between the potential for energy recovery of the initial identified sites in Ireland and Spain and the population served, and the total population of the different countries. The corresponding equation and methodology followed is described in detail in WP4.

The extrapolation showed a total potential for energy recovery using MHP of 75 GWh per year, corresponding to a nominal total power potential of 8556 kW. In this case, the potential is significantly lower than the potential found for the drinking water sector. One of the main reasons is that the evaluation of the potential for the wastewater sector was based on the discharge licenses, so the only available energy was the corresponding to the difference in height, between the WWTP and the riverbed. In contrast, the hydraulic analysis of the water distribution networks for the drinking water sector took advantage from overpressures.

Considering an average total cost ratio of 3772.6 €/kW obtained for MHP projects based on PAT technology in the wastewater sector, the potential market would be around M€ 32.3 in the set of countries analysed. The total unit cost ratio in this sector, which generally lower head pressure values, was much higher than in the case of the drinking water sector, due to how the flow and head pressure rates impact on the cost equation. The distribution of the potential market for MHP between the different countries in the wastewater sector is displayed in Fig. 24.

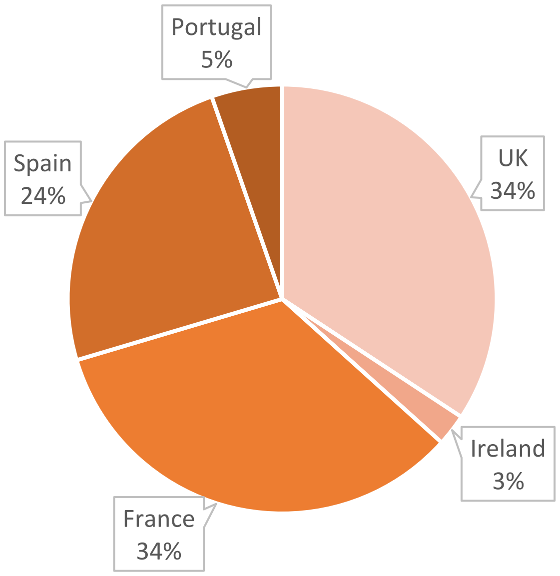


Figure 24. Percentage distribution between the different countries of the potential market for MHP in the wastewater sector

4.4.3. Irrigation sector

The potential for energy recovery through MHP in the irrigation sector was based on the results obtained after the analysis of 18 irrigation networks in Southern Portugal and Spain, extrapolated then to the main irrigation areas in both countries. The details about the extrapolation methodology can be found in WP4 report.

In this case, the extrapolation of the MHP energy recovery potential in the irrigation sector considered the south of Portugal, including the Alentejo and Algarve regions, with a total covered surface of 143424 ha, and the area with localised irrigation fed by surface water sources in Spain, with a total are of 1.48 Mha. The potential power to be installed for MHP energy recovery reached a total of 120.5 MW. In contrast to the rest of analysed sectors, which are considered to have an operating regime of 24 h 365 days a year, the irrigation sector has a very seasonal activity. Therefore, in this case, the installed power to produced energy conversion was lower, reaching a total of 244.85 GWh, distributed between the two countries. However, in market terms, the figure to consider would be the nominal power to be installed.

Considering an equipment average total cost of 1865 €/kW obtained from the set of irrigation networks analysed, using the proposed methodology, the potential market in the irrigation sector, for Southern Portugal and Spain would reach around M€ 224.7, with the percentage distribution showed in Fig. 25.

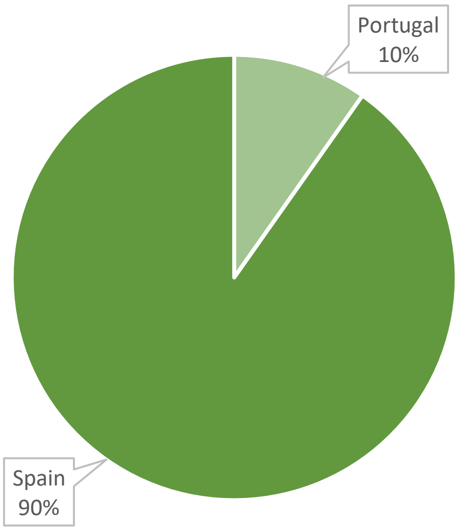


Figure 25. Percentage distribution between the different countries of the potential market for MHP in the irrigation sector

4.4.4. Industry

The extrapolation of the potential for energy recovery in the industry sector was based on the results obtained from the discharge licenses in Spain, as the sites analysed in some private industries in Ireland and Portugal were considered insufficient for a country scale extrapolation, as detailed in the WP4 report. The extrapolation considered the importance of the industry sector in the gross domestic product of each contry. Thus, the total potential for energy recovery with MHP in the private industry sector reached 46.69 GWh for the set of countries analysed.

As discussed in WP4, the internal analysis of the water distribution networks in the private industries could increase significantly the potential for energy recovery in this sector, taking advantage of the excess pressure or head and not only of the wastewater discharges. However a larger volume of detailed data, not available to date, would be required.

Considering the average ratio obtained for the total cost for MHP installations based on PATs in the private industry sector, which amounted to 3998.9 €/kW, the potential market for the set of countries included in REDAWN would reach around M€ 21.3, distributed between countries as showed in Fig. 26.

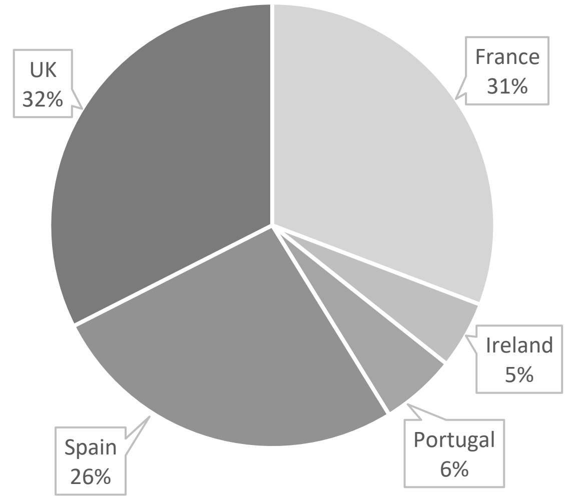


Figure 26. Percentage distribution between the different countries of the potential market for MHP in the industry sector

Again, as shown in the wastewater sector, for the private industry, in which the available head pressure was lower in the different sites, the total cost ratio was significantly higher compared to those sectors in which the pressurised network has been analysed (drinking water sector and irrigation).

4.4.5. Total potential market

The analysis of the potential market, based on the estimations developed by the extrapolation of the results for the different countries and sectors, showed a total potential market between M€ 457.6 and 707.9. The drinking water and irrigation sectors represented the largest contribution, with approximately 91-94% of the total potential market (Fig. 27). In both cases, the analysis of the potential for MHP energy recovery, and thus the results of the potential market, were based on the internal analysis of pressurised water distribution networks. However, the results obtained for the private industry and wastewater sectors came from the analysis of the discharge volumes, with the difference in height (between the facility and the discharge point) as the only exploitable energy. This points out that a large proportion of the potential lies in the recovery of the energy previously lost as an excess pressure. Therefore, as noted in WP4, the internal analysis of the water distribution networks in private industries would significantly increase the potential market of MHP technology in this sector.

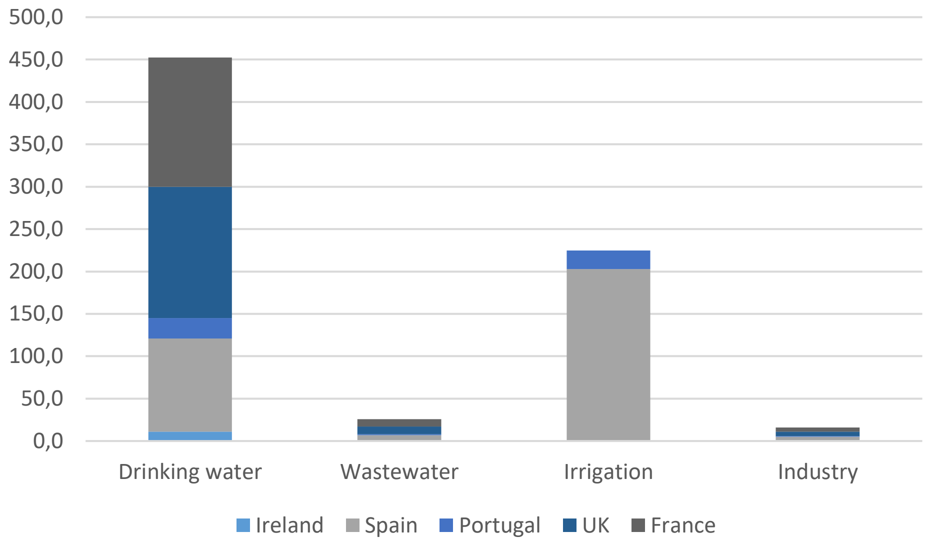


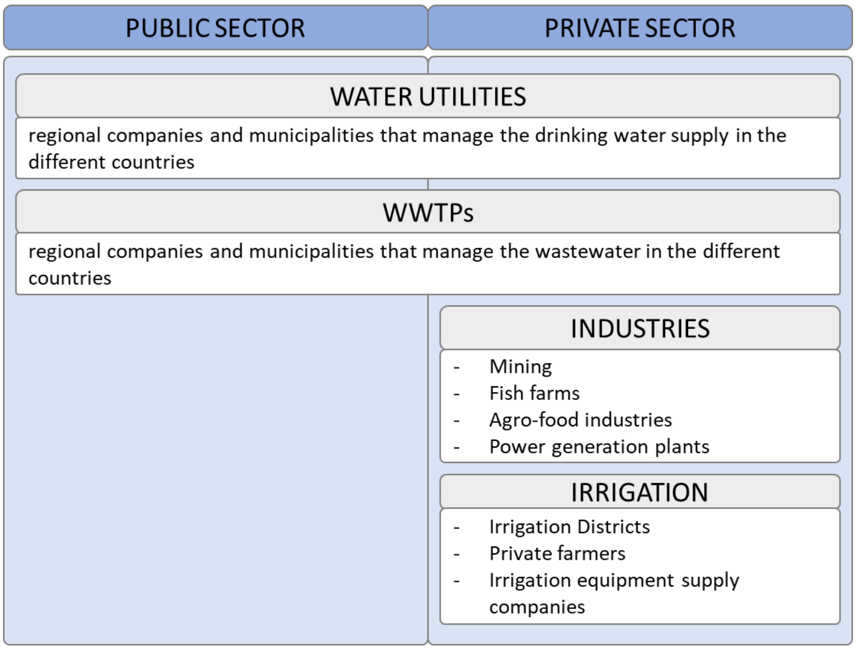
Figure 27. Potential market in M€ for MHP in the different sectors and countries analysed.

Undoubtedly, the results obtained for the potential market of MHP technology show a wide business field for companies involved in the production of micro-hydro technology and those engaged in offering related services. Furthermore, in this case the calculations have been restricted to the countries involved in this project. However, the extension of these results to other countries and even to other continents offers a promising future for the MHP sector.

4.4.6. Customers segments

The customers segments are in this case as wide as the water industry sector itself. Thus, in the case of the drinking water sector, the customer segments correspond to the companies that manage the water distribution networks, and thus the drinking water supply, in each of the regions. This is defined by the type of management in each country, encompassing private, public and mixed companies. Similarly, the wastewater sector also depends on a private, public or mixed management, which will depend on each region.

However, for the industry and irrigation sector we mainly focus on private companies. The private industry comprise a large number of typologies, which in a very generalised way, and considering those sectors which involve the use of a significant volume of water, could be grouped into mining, agri-food, energy, construction, fish farms, and chemicals companies, among others. A large part of the irrigation sector, in particular pressurised irrigation, is encompassed in irrigation districts, i.e. large groups of farmers with an extensive network of pressurised pipes supplying water to all of them. Therefore, these irrigation districts would represent an interesting customer segment, to which other farmers not associated with irrigation districts, or companies focussed on irrigation projects and equipment supply, could be added.



regional companies and municipalities that manage the drinking water supply in the different countries

regional companies and municipalities that manage the wastewater in the different countries

Figure 28. Main customers segments for MHP in Europe

These potential customer segments can in many cases be contacted directly or in other cases, it may be interesting to establish commercial channels through partners, who already have a wide portfolio of customers to whom they supply their services and can offer MHP technology as a complementary technology for their installations.

4.5. Competitors

Usually, the study of the competitors tries to identify the aspects that differentiate their services/products from the offered by the rest of companies. In global terms there is a large number of companies manufacturing and/or installing turbines, as well as those offering maintenance services, in the market.

4.5.1. MHP versus alternative RE sources

Beyond MHP technology, competition should also include companies specialised in alternative solutions and technologies for energy supply. In this case, those solutions would be represented by other renewable energy sources that could solve the partial or total energy supply, reducing the energy demand from the grid or fossil fuels consumption, and thus, the corresponding cost and CO_2 emissions. The alternative green-energy technologies in this case could be mainly represented by wind and solar energy. In the case of wind energy, adequate wind levels are required, exploited by a wind turbine that would provide a partial energy supply, exploitable in the surroundings or with the possibility of feeding it into the grid. In the case of solar PV energy, a properly oriented surface in a well irradiated area is required for the installation of the photovoltaic panels. In this case, the generation of energy would coincide with the sunshine hours, and this could partially cover the energy needs of the installation and/or be sold to the grid. In both cases, energy production would depend mainly on weather conditions, wind speed, and irradiance and temperature, respectively, while when a MHP plant is integrated in a drinking water network or treatment plant, wastewater treatment plant, industry or irrigation network, energy production coincides in time with the activity/operation hours of the facility.

A significant and continued decline in the cost of solar PV electricity has been experienced in the last years. Solar PV projects have a highly replicable and modular nature. This means that the particular characteristics of each project have less impact on the cost than in the case of other technologies, with the biggest difference being subject to the country. Although there are still variations both within the countries and between countries, installation costs are expected to converge as local supply chains become more competitive and experienced. The global cost of projects based on onshore wind has followed a declining trend, thanks to the continued reductions in total installed costs and improvements in the average capacity factor, with wide variation between countries.

Hydropower, in turn, is a low-cost energy production option, which in addition offers cheap electricity storage and large-scale flexibility in large projects involving reservoirs. Hydropower plants can be constructed in a variety of sizes and characteristics. These project-specific characteristics make the cost of the technology differ more between projects. Average data for recent years show an increase in the average cost of hydropower. However, this is due to the fact that most of those projects were developed to electrify isolated areas, where the cost of installation is usually higher than in areas with grid access.

The Levelised Cost Of Energy (LCOE) shows the current total cost of built/installed and operation of an installation for energy generation through its useful life. This LCOE measures the total lifetime costs and divides them by the energy production during all the years of operation, so that it is measured as an economic unit (USD or €) per energy unit (kWh). Figure 28 summarises the evolution of the LCOE for these three renewable energy sources in the period 2010 to 2019, with hydropower as the most cost-effective technology, and solar PV as the one that has experienced the greatest cost reduction.

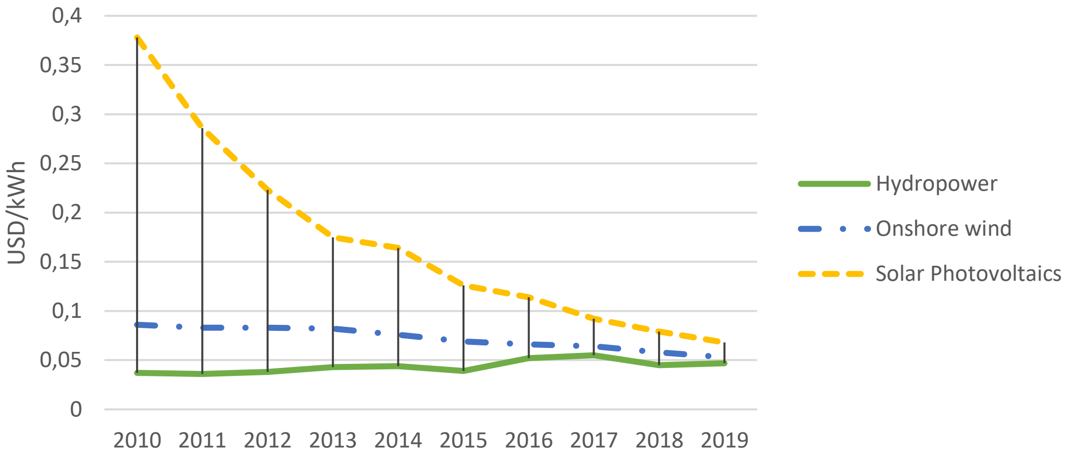


Figure 29. Evolution of the global average of the Levelised Cost Of Energy per technology in the last nine years.

*Data collected from (IRENA, 2020)

4.5.2. Manufacturers and service providers

There are several manufacturers and service providers, as well as trading companies, related to conventional hydropower turbines in the global market. Some of those are Gilkes, Andritz Hydro, Ossberger, Cink, Lucid Energy, Canyon Hydro, Hydrospon, Natal Energy.

These commercial solutions are based mainly on hydraulic turbines, for mostly large hydroelectric power plants, with some of the companies specialising in smaller installations. In the case of Europe, there are also several options for turbine technology suppliers, summarised in Table 7.

Table 7. Some of the suppliers related to hydropower technology in Europe

Company	Country	Technology
ATB Riva Calzoni SpA	Italy	Small-hydropower
Capstone Turbine Corporation	Spain	Micro-turbine energy systems
CinK Hydro- Energy k.s.	Czech Republic	Small and medium sized hydropower
CKD Blansko Holding A.S.	Czech Republic	Hydro-turbines
Dyna Vec AS	Norway	Hydro-Turbines
Easy Hydro Solutions Ltd	Ireland	Pump-as-turbines
Elpower	Italy	Inverters
ENCOSyst	France	Small hydro and medium capacity
Energi Teknikk AS	Norway	Hydro-turbines
ENERSET	Bulgaria	Generators for RE production
Etaeval	Switzerland	Mechanical measurements and simulations in hydroelectric plants
Gamesa Electric	Spain	Hydro-electric generators
Geppert Hydropower	Austria	Electromechanical equipment for hydroelectric power plants
Gilbert Gilkes & Gordon Ltd	UK	Small hydropower
Global Hydro	Austria	Hydropower plant technology
Gugler Water Turbines GmbH	Austria	Water turbines
Hydro energy	Poland	Hydro-turbines
Hydro Power Plant SAS (HPP)	France	Hydro turbines

	Hydroalp S.R.L.	Italy	Hydro-turbines
	HydroBox NV	Belgium	Hydropower solutions
	HydroQuest SAS	France	Hydro-Turbines
	Ingeteam	Spain	Inverters and generators
	IREM SpA	Italy	Hydro-turbines
	Litostroj power	Slovenia	Hydro-turbines
	LTi Reenergy	Germany	Electrical inverters, energy conversion.
	Ossberger GmbH Co. KG	Germany	Water turbines
	Powerturbines S.L.	Spain	Pumps as turbines
	Sea-Lix AS	Norway	Small-hydropower
	Smart Hydro Power	Germany	Turbines and energy management
	Tecnoturbines	Spain	Water turbines
	TidalStream Ltd.	UK	Tidal power- Undersea currents
	Tschurtschenthaler turbinenbau	Italy	Hydro-turbines
	Wasserkraft Volk AG	Germany	Small and medium-sized hydropower
	Wavepower Technologies	UK	Turbines for waves

Most of these companies are focused on the manufacture and/or distribution of turbines, inverters and controllers, but very few of them are focused on Pumps as Turbines. PATs transform the hydraulic energy of water into electrical energy, by means of a rotational movement in reverse to that of the normal operation of a pump. One of their main advantages compared to the use of conventional turbines is their low cost, as they take advantage of the chain production of pumps and allow a wide range of hydraulic solutions to be offered. Therefore, the low cost and the wide range of solutions linked to PATs, coupled with the limited number of companies specialised in the PATs, could be the main strengths that could be exploited for the implementation of a business project based on micro-hydro energy projects.

4.6. Conclusions

The business model section of this report did not focus on the development of a traditional business model document for a specific company as such. The aim of this section was to give an overview of the potential market as well as the current state of the sector, in view of the possible business potential in the field of micro-hydropower technology. This information is provided as the basis for the formulation of specific business models by individual companies capitalising on the result of the REDAWN project.

The potential market has been assessed on the basis of the extrapolation of the energy recovery resources developed under WP4 for the different sectors (drinking water, wastewater, industry and irrigation) and countries (UK, Ireland, France, Portugal and Spain) included in REDAWN. This assessment has shown a total potential market between M€ 457.6 and 707.9, which could be even higher if private water distribution networks in industry could be examined in more detail. From the collected data, the drinking water sector has the greatest potential, together with the irrigation sector, in those countries where irrigated agriculture is relevant, both sectors equipped with a large pressurised water distribution network.

Obviously, as shown previously, there are currently many companies involved in the commercialisation of technology and services related to hydropower, but few focus on the development of small projects and even fewer work with PATs as a low-cost alternative for energy recovery in the water sector. Therefore, the future of micro-hydropower can have a great untapped potential which, supported by a favourable legislative environment, will help companies to find a new niche market with great interest.

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