LIFE NEXUS: First European inventory of micro-hydroenergy recovery potential in the water industry

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Introduction

Water and energy are two of the most important resources of the 21st century. In particular, **cities** are a framework where this **water-energy nexus** is becoming critical due to demographic movements, economic growth and global change pressures. The current context of water scarcity and need **for low carbon intensity solutions** is making it a challenge to continue to deliver core urban water services without increasing the impact on the environment. LIFE NEXUS Project proposes a breakthrough by **considering urban water networks as a source of renewable energy**. Despite the odds, to date limited analyses have been carried out to identify the energy recovery potential in the urban water cycle (UWC) [1-4].

Supply water is transported by pressured piping grids, while drain and sewage systems are usually gravity fed. Both types of grids may hold untapped energy deriving from abundant pressure (water head) or the kinetic energy (water flow). Usually, these points with excess of energy are located in:

1) Storage/service reservoirs (SRV) gravity fed or water treatment works in the raw water network located in upland areas and feed into Drinking Water Treatment Plants (DWTPs), either at catchment or distribution stages,
2) Wastewater systems, either upstream or downstream of Waste Water Treatment Plants (WWTPs), collection or discharge stages,
3) Pressure reducing values (PRVs), are hydraulic devices that maintain pre-set pressure ranges and are installed to relieve the excess pressure and release it as waste heat,
4) Break pressure tanks (BPTs), whereby the pressure, kinetic and potential energy within the flow are dissipated to the atmosphere.

Theoretically, all PRVs and BPTs could be replaced with **in pipe generators**, maintaining the same control on water flow and pressure whilst producing usable electricity ("green electricity"). It is important to mention that recovering energy at these locations will have no impact on the flow or pressure to downstream consumers. Furthermore, the pressure reduction is correlated to a decrease in the water leakages [5].

LIFE NEXUS Project is evaluating the technical / economic and environmental feasibility of the energy recovery in water networks by means of Small Hydropower Plants (SHP). Among the different available machines (traditional turbines or adapted machines), LIFE NEXUS demonstration will be focus on the innovative Pump as Turbine (PaT), a type of adapted machine, that is becoming the technological solution for micro-hydraulic projects (≤ 100 kW) [6-8]. The main advantages of these machines are their immediate availability for installation and lower cost compared with conventional machines. A **cutting-edge integration** of a PaT machine together with battery storage is being carried out to enhance the possibilities of the energy management. This innovative system will be installed at the entrance of the Porma Drinking Water Treatment Plant (DWTP) located in Valdefresno, a small village nearby the city of Leon (Spain). Once they will be fully operating the energy generated will cover the total energy demand of the installation.

In parallel to the previous demonstration of the PaT technology, LIFE NEXUS has carried out the **1st European inventory** of the **energy recovery locations**, including both **new sites** and **existing hydropower plants**. Although the catalogue was initially intended to harbor **urban sites**, finally it also has included **industrial and irrigation locations**, in order to boost energy harvest in other sectors. This abstract is focus on this LIFE NEXUS inventory and describes the main outcomes obtained so far within the Project.

Methodology

The information contained in the catalogue is georeferenced, mapped in layers according to their location and is accessible through a web platform. For **data collection**, a questionnaire based on an Excel platform was created, which contains 16 or 19 questions depending on the type of location. This questionnaire for data collection is available through the LIFE Project website in the Community Menu [9]. For the **implementation of the online survey**, the **LimeSurvey** open source **Tool** was used.

For the **implementation of the database**, the **GeoJSON file** as database was the method chosen for different reasons: (i) The geometrical requirements are very low, because only Points will be stored, so all the potential that the database could provide is no needed and (ii) The data will not be update frequently, so the database will be mainly only for reading, functionality that GeoJSON can cover perfectly.

The information has been published as a **geo-referenced database** [10]. The main characteristic of a GIS (Geographical Information System) is that it is possible to work with data located in space with reference to a geographic coordinate system, which allows us to generate georeferenced maps. Leaflet is used as the web map client. It is an open-source JavaScript library for mobile-friendly interactive maps. The main principles of Leaflet are the simplicity, performance and usability. It is well-documented and there are a wide variety of plugins that enables to extent the tool functionality. Leaflet is used to show the data contained in the json in a map.

Regarding the base map, in our case OpenStreetMap (OSM) and Mapbox will be used. OSM is created by a collaborative community for sharing free geographical data around the world in a free editable map of the world. This community add, verify and update the data using aerial images, GPS, maps and another free data so it is very complete. Map box is also an open source mapping platform for custom designed maps that contains data based in OSM. The visualization module is available through the Project website:

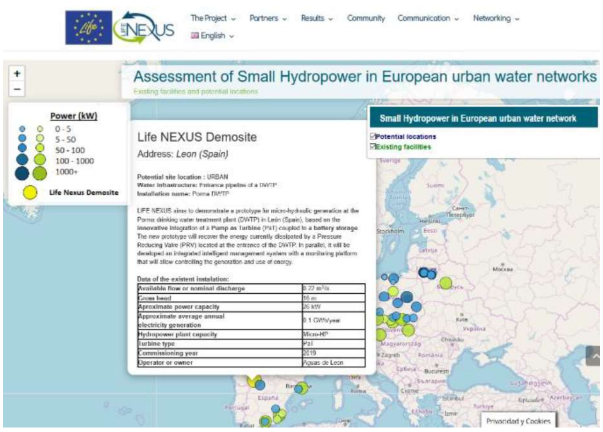

Fig.1. Visualisation of micro-hydro potential locations in urban water networks

CARTIF and AQUATEC have been responsible for the contacts in Spain. Then, IMP-PAN and ASU were in charge of Poland and Lithuania, respectively.

Results

At this moment, the inventory contains **104 energy recovery locations** (71 potential and 33 existing Hydropower plants) from **10 different European Countries:** Spain, Lithuania, Poland, Austria, Belarus, Czech Republic, Germany, Italy, Slovakia and Switzerland.

Potential locations

LIFE NEXUS inventory has 71 potential locations, located in Lithuania (25), Poland (23) and Spain (23). The approximate power capacity derived from these locations, assuming a generation efficiency of 75%, is **2.97 MW**. The **theoretical annual electricity generation** is **11.87 GWh/year** assuming 4000 hours of operation per year.

Regarding the type of locations, 52 sites are located in the UWC, 18 are placed in irrigation channels and one is a "mixed" site for urban water supply and irrigation.

37 of the potential locations are located at a WWTP (downstream or upstream), 22 are SRVs located at the entrance pipeline of a DWTP. Finally, there are nine PRVs and three BPTs, all of them located at the entrance to the distribution network.

Regarding the theoretical approximate power capacity (considering 75% of efficiency in the turbine), eight of them are Mini-hydraulic (≤ 1 MW), and the rest are Micro-hydraulic (≤ 100 kW).

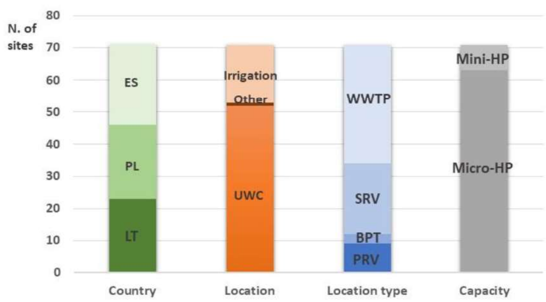

Fig.2. Characteristics of the potential energy recovery locations in the LIFE NEXUS inventory

Assessment of potential locations at country level

Lithuania: Due to the country's topographic conditions – a purely lowland country, only sewage (wastewater) networks with free gravitational flow can be attractive for the harvesting water energy. Drinking water distribution systems are artificially pressurised and cannot be used for energy recovery. Only one site was spotted in the drinking water distribution network with a pressure-reducing valve. The urban water networks of the two largest country's cities - the capital Vilnius and Kaunas were studied in depth along with a dozen smaller towns. So far, some 25 potential sites with their main characteristics were identified upstream or downstream waste water treatment plants (WWTP). All of the power capacities are below 100 kW (eight of them below 10 kW) [11].

Poland: Potential sites are located in the sewage networks and in WWTPs with free gravitational flows.

Most of the power capacities are below 100 kW (five of them bellow 10 kW). However, there are two potential sites very promising with 201 kW and 525 kW located in a WWTPs and in a SRV respectively.

Spain: four of the sites identified are located at the entrance of urban water distribution networks, being three of them PRV devices, while the other is a BPT. Approximate power capacities are in the interval 36 – 74 kW. The rest of the locations in Spain are located in irrigation channels, being one of them a "mixed" site for urban water supply and irrigation. Most of these locations are secondary storage reservoirs (SRVs) and show very different capacities: 11 sites bellow 10 kW and four sites with capacities above 150 kW.

Replication studies in potential locations

Thirty-five locations out of the total 71 have been selected for the so-called "**replications studies**", where the technical-economic viability of new mini-hydraulic projects is being assessed, considering the regulatory and policy context of each country.

In Lithuania, the viability of SHP energy recovery was performed **at eight potential locations**: three WWTPs, four wastewater collectors (upstream of WWTPs), and one site in the drinking water network. The latter represents a separate case.

Existing installations

The 33 existing hydropower plants are located in nine different European countries: Belarus (1), Slovakia (1), Germany (1), Italy (1), Switzerland (3), Austria (4), Czech Republic (6), Poland (6) and Spain (10). The **total installed power output** of these installations **is 14.82 MW and the annual electricity generation is 73.8 GWh/year.**

Thirty of the installations are placed in the UWC and the other three are located in several industries: metallurgy, power plant and oil refinery.

Regarding the location in the UWC; one turbine is located in the cooling system of a metallurgical industry and other one is located in a desalination plant. Then, seven turbines are located at the entrance of a DWTP, nine are in the downstream of a WWTP and finally 15 are at the entrance of a drinking water distribution network.

Regarding the type of turbine, there are two others (cross-flow or pressure exchanger), four Kaplan, eight Pelton, nine Francis and ten PaTs.

Finally, regarding the hydropower plant capacity, there are three SHPs (1-10 MW), 17 mini-hydraulic plants (100 kW – 1 MW) and 13 micro-hydraulic plants (≤ 100 kW).

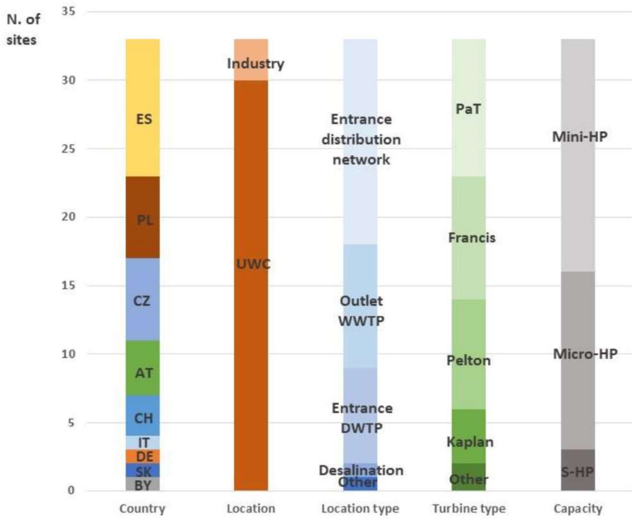

Fig.3. Characteristics of the existing installations included in the LIFE NEXUS inventory

Assessment of potential locations at country level:

Lithuania: No existing hydropower plants operating in water and waste water infrastructure have been identified so far in this country. The same is for other Baltic countries.

Poland: six hydraulic energy recovery installations are currently under operation in Poland. Four of them operate in the UWC and the other two are located downstream the WWTPs of the PKN Orlen Oil Refinery (130 kW Francis turbine) and the Skawina Hydropower Plant (1.4 MW Kaplan turbine)

Spain: A number of ten hydraulic energy recovery installations are operating in the country and all of them operating in the UWC. Nine of the facilities are micro-hydropower installations (power capacity in the range of 11-90 kW), involving seven PaT machines, one Francis turbine and one cross flow turbine. Finally, there is an energy recovery device (Pelton turbine) in a desalination plant with a power capacity of 514 kW.

Replication studies in existing installations:

One hydropower plant out of the total 33 has been selected for the so-called "**replications studies**". It is rehabilitation of a decommissioned energy recovery installation in the PKN Orlen Oil Refinery in Poland. Several alternatives for the substitution of the Francis turbine by other turbines located in different locations of the plant are being studied.

Conclusions

(1) Micro-hydropower plants are an appropriate solution to recover the untapped energy existing in water networks, and thus, they can support the clean energy transition in the European water industry.

(2) LIFE NEXUS inventory has mapped 71 potential locations along Poland, Lithuania and Spain, which all together lead to an approximate "sleeping" potential of 2.97 MW. The energy generated can be used on site, as for the case of the LIFE

NEXUS demosite, where the energy harvest by means of the PaT will cover the total demand of the installation .

(3) Most of the potential locations included in the inventory have a capacity below 100 kW (micro-hydropower) and are located mainly in WWTPs (downstream or upstream) or in SRVs located at the entrance pipeline of DWTPs.

(4) LIFE NEXUS inventory has mapped 33 existing Hydropower plants along Europe, with a total installed power output of 14.82 MW. Most of the installations are located in the UWC, mainly at the entrance of a DWTP, at the entrance of a distribution network, or downstream of a WWTP. PaTs are the most installed machines in this energy recovery plants, followed by Francis and Pelton turbines. Regarding the capacity, almost have of them are mini-hydropower plants and the other half are micro-hydropower plants.

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LIFE
Programme

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