WatefCon 2018: Future of Water in Europe
Aveiro 5-7 September 2018

Hydropower energy recovery in water pipe networks: spatial regression analysis using GIS, assessing the correlation between energy recovery potential and geographical data

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REDAWN
Reducing Energy Dependency in Atlantic area Water Networks

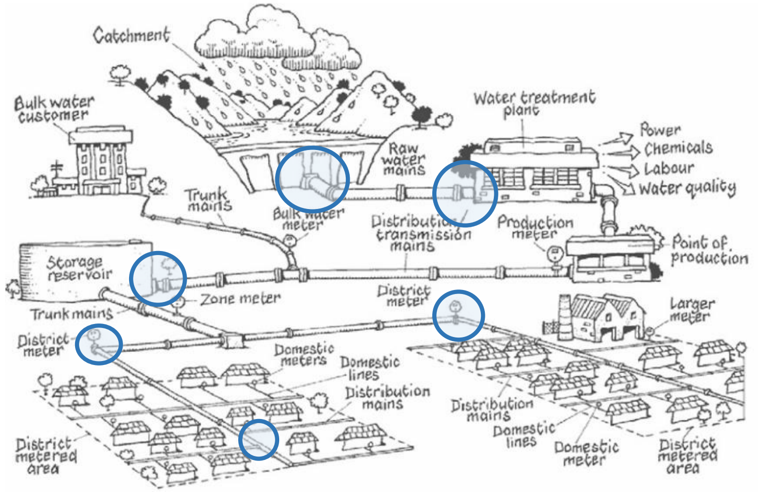
Interreg Atlantic Area
European Regional Development Fund
EUROPEAN UNION

INTRODUCTION

- Water Pipe Networks = Water Supply Networks + Wastewater Networks
- The water industry is the fourth energy intensive industry in the UK → 5 tonnes CO_2 + 7.9 TWh of energy

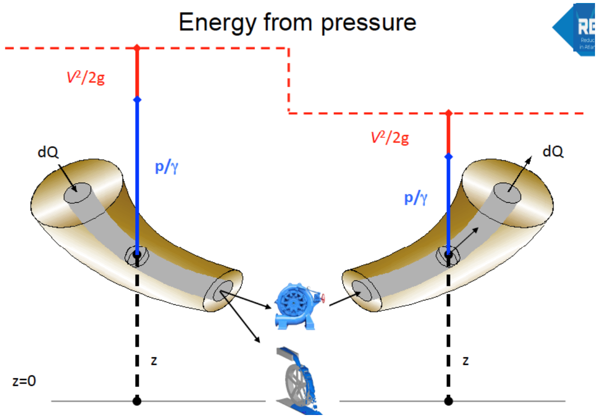
- Methods to improve sustainability ⇨ Micro-hydropower energy recovery (MHP)

Water Supply Networks (WSNs)



Source: Queensland Environmental Protection Agency and Wide Bay Water Corporation (2004): Managing and Reducing Losses from Water Distribution Systems. A series of 10 manuals

- Large hydropower 10-1 MW
- Small hydropower 1 MW – 100 kW
- Micro-hydropower 100-1 kW
  - SRs
  - CVs
  - PRVs
  - BPTs



INTRODUCTION

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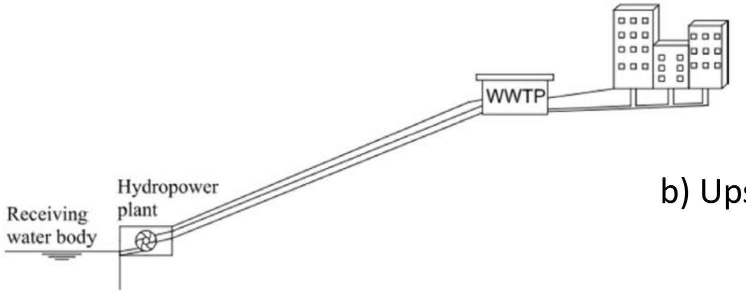
- The water industry is the fourth energy intensive industry in the UK → 5 tonnes CO2 + 7.9 TWh of energy
- Methods to improve sustainability ⇨ Micro-hydropower energy recovery

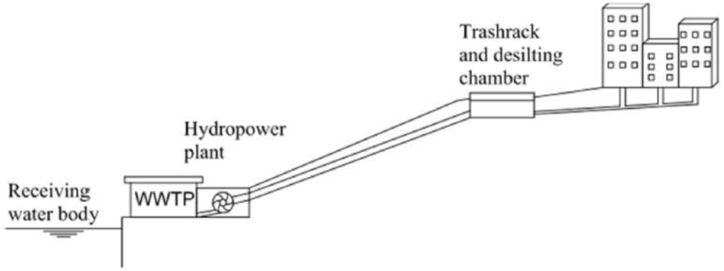
Wastewater Networks (WWNs)

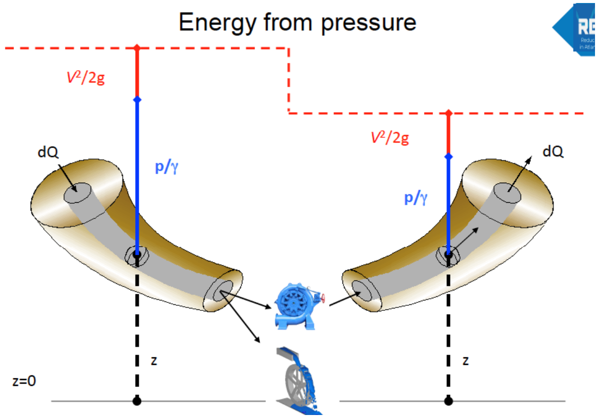
a) Downstream treated effluent micro-hydropower plant



Source: Bousquet et al. 2017

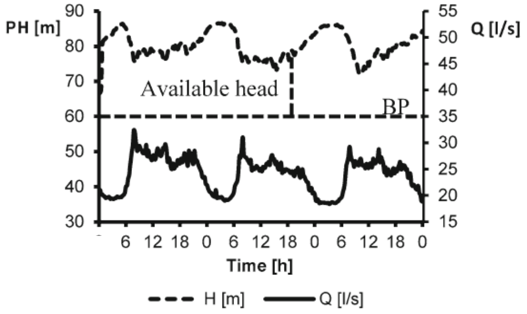
b) Upstream sewage water micro-hydropower plant

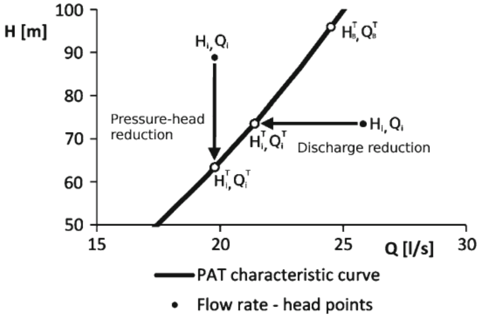




INTRODUCTION

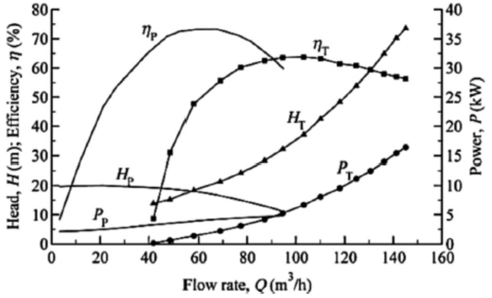
- Barriers which prevent exploitation
  - Technical
    - Variations of flow and pressure





Source: Carravetta et al. 2012

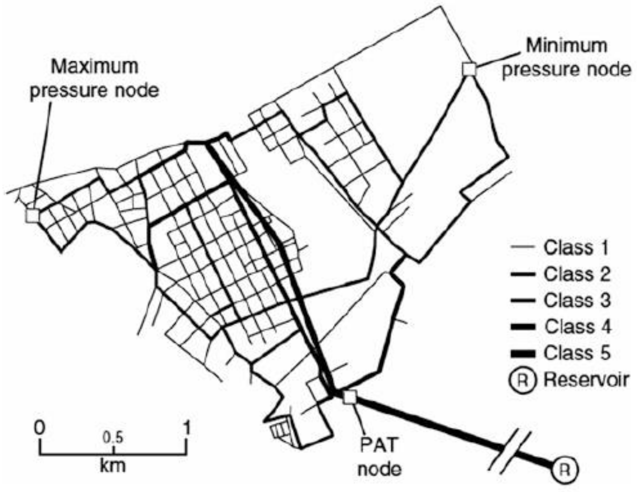
    - Pressure control
    - Conventional turbines cannot be scaled down in economically viable way
    - Lack of performance curves for Pump-As-Turbines (PATs)



Source: Binama et al. 2017

INTRODUCTION

- Barriers which prevent exploitation
  - Non-technical
    - Lack of incetives
    - Lack of awareness about the existing resource available
    - Lack about awareness about the environmental and economic impact

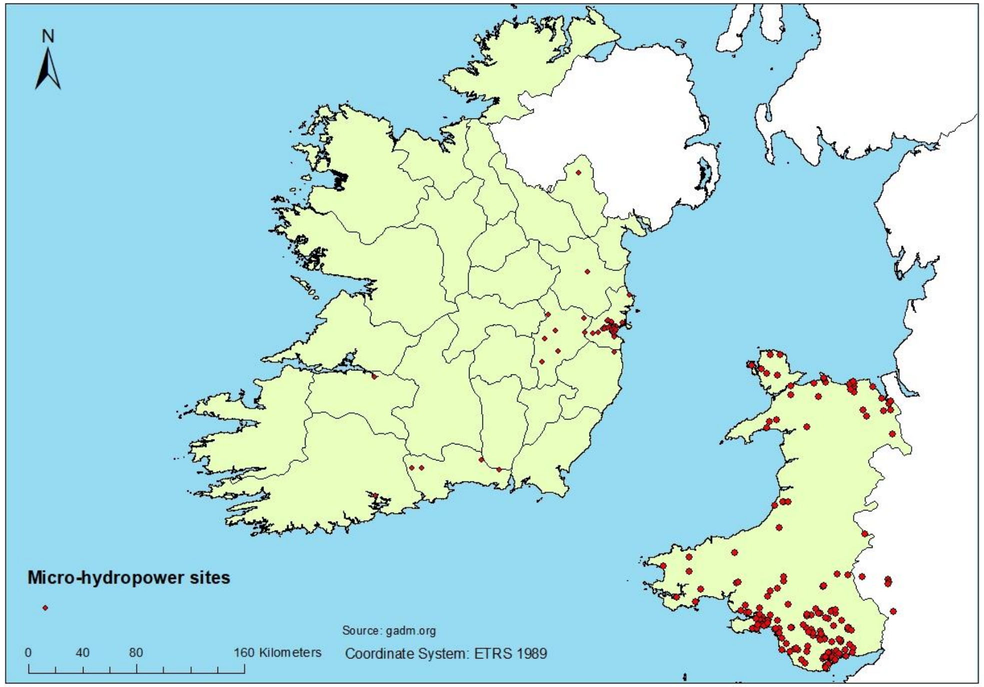


- Why is so hard to assess the potential of a large geographical coverage?
- Network models either do not exist or are not publicly available for the whole area of interest
- In this work: Is there a correlation between the MHP potential of sites and geographical data?

METHODS

Studied sites

- Locations of valves with excess pressure



- 51 sites in Ireland and 187 sites in Wales (Provided by Irish and Welsh Water)
  - SRs
  - CVs
  - PRVs (2/3 of the set)
  - BPTs
  - Inlet and outlet to WWTPs
- Data available for each site
  - Longitude and latitude coordinates
  - Site type
  - Mean annual flow and pressure (2011)

Calculating the potential energy that can be recovered

$$Power = \rho g Q H \eta \ \text{[kW]}$$

η = 0.65

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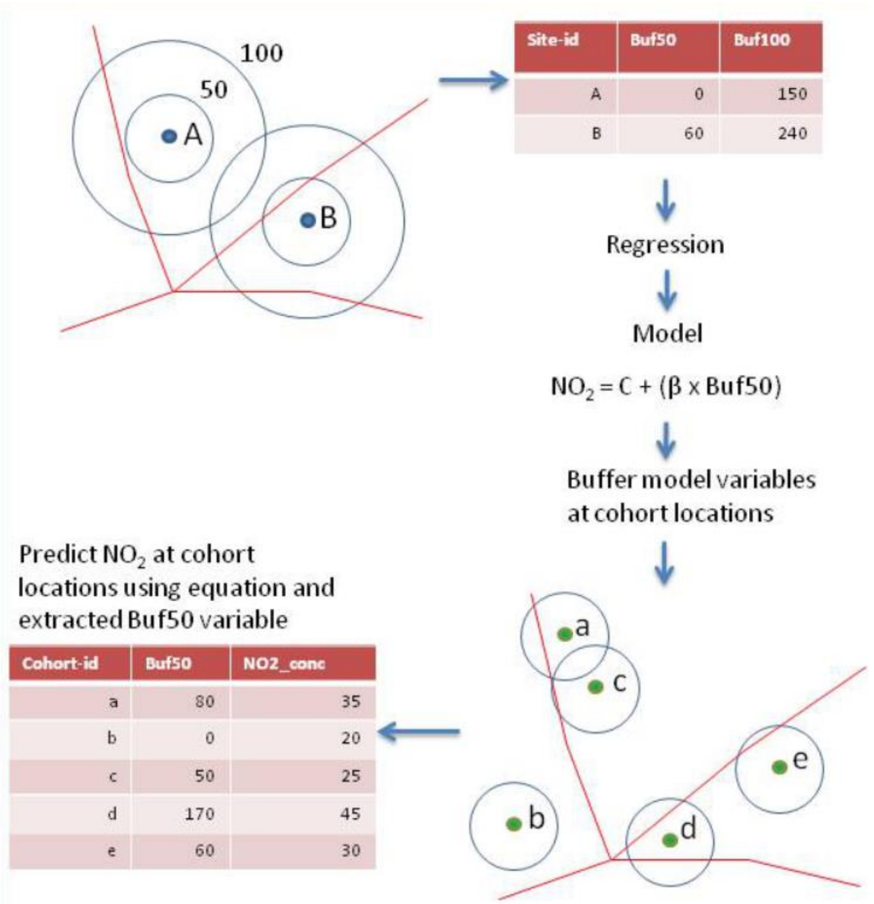
SPATIAL REGRESSION ANALYSIS

- The aim of the research: Total MHP potential in the Atlantic Area part of Europe WPNs
- Impossible to collect data about all sites in the region of interest!
- Idea for the approach: Air quality modelling → Land Use Regression (LUR)
- Analogy: Dependant variables → $Power = \rho g Q H \eta$ [kW]
- Challenge: Finding independent variables which would explain varioation of the potential without have the networks to which the sites belong



Source: http://www.integrated-assessment.eu

SPATIAL REGRESSION ANALYSIS (Population)

$Power = \rho g Q H \eta$ [kW]

Q = f (population downstream)

Q = f (type of infrastructure) → $Q_{SR} >> Q_{PRV}$

Reference System: ETRS89

Type and Resolution of the input data: Grid with cell size 1x1 km^2 (ec.europa.eu)

ArcMap

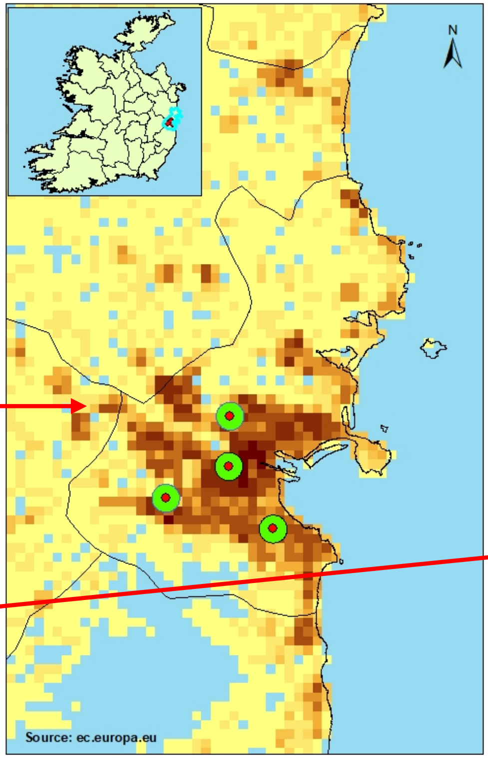
Type and Resolution of extracted data (variables):

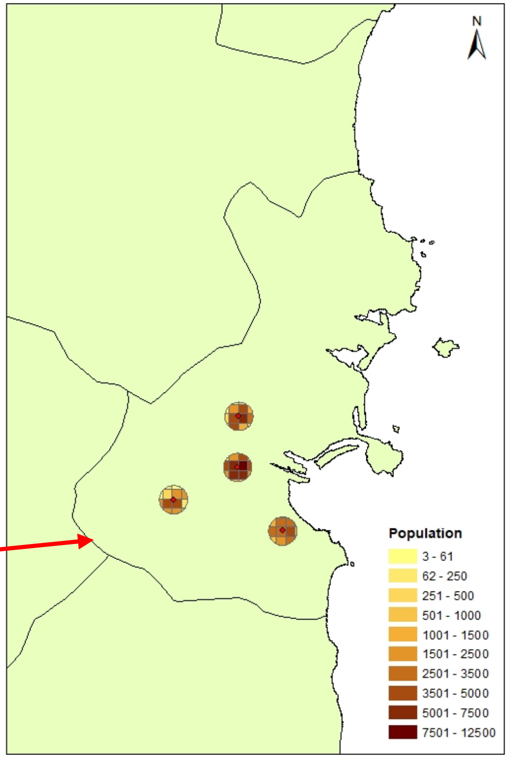
- Population inside the buffers: 1,3 and 5 km

$$\frac{Part\ of\ the\ cell\ overlaid\ with\ the\ buffer}{Area\ of\ the\ cell(1x1km)} \times population\ within\ the\ cell$$

- Population inside a grid cell: 1x1 km^2

Extraction and calculation of population variables

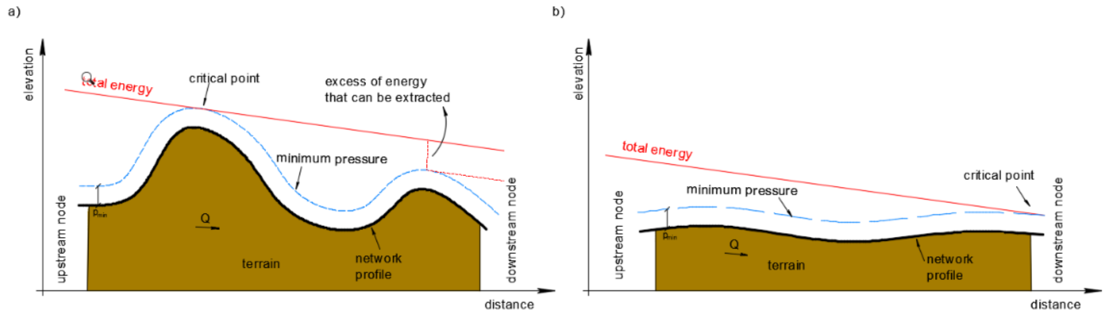




Source: The statistical office of the European Union (ec.europa.eu)

SPATIAL REGRESSION ANALYSIS (Topography)

- $Power = \rho g Q H \eta$ [kW]
- Excess pressure = f (terrain variability)
  - Hilly vs flat terrain
  - Large difference between a source and the rest of a network



- Tricarico et al. 2017. → $I_{Net} = \dfrac{H_{Tanks,max} - Z_{min}}{L_{Tot,Net}/N_{Tanks}}$

I_{Net} ↗ , Energy recovered by means of PATs ↗

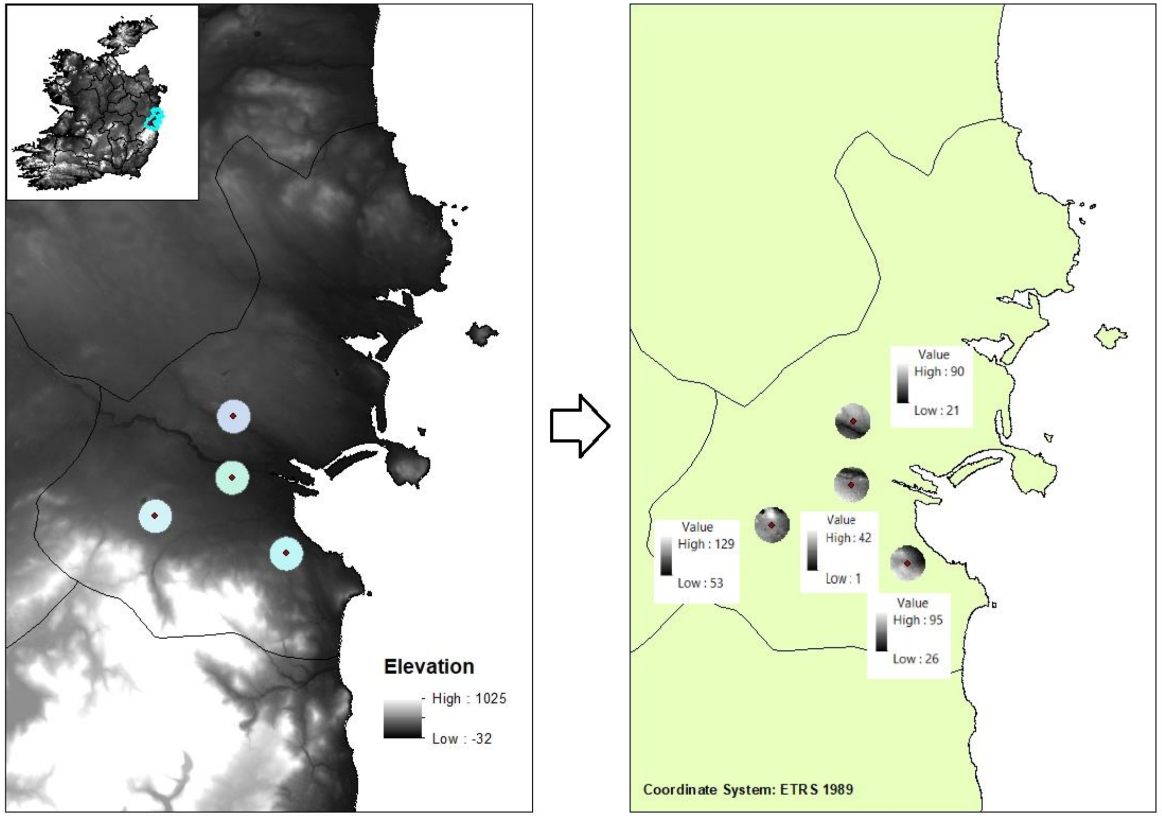
SPATIAL REGRESSION ANALYSIS (Topography)

- Type and Resolution of the input data:
  Digital Elevation Model (DEM) with cell size of 1x2 arc-second (≈30x60 m)

⇩ ArcMap

- Type and Resolution of the extracted data (variables):
  - SD of the clipped DEM buffers: 0.5,1,3 and 5 km
  - Slope

Extraction and calculation of topography variables



Source: United States Geological Survey website (www.usgs.gov)

RESULTS

Gallagher et al. 2015. MHP site classification in Ireland and Wales

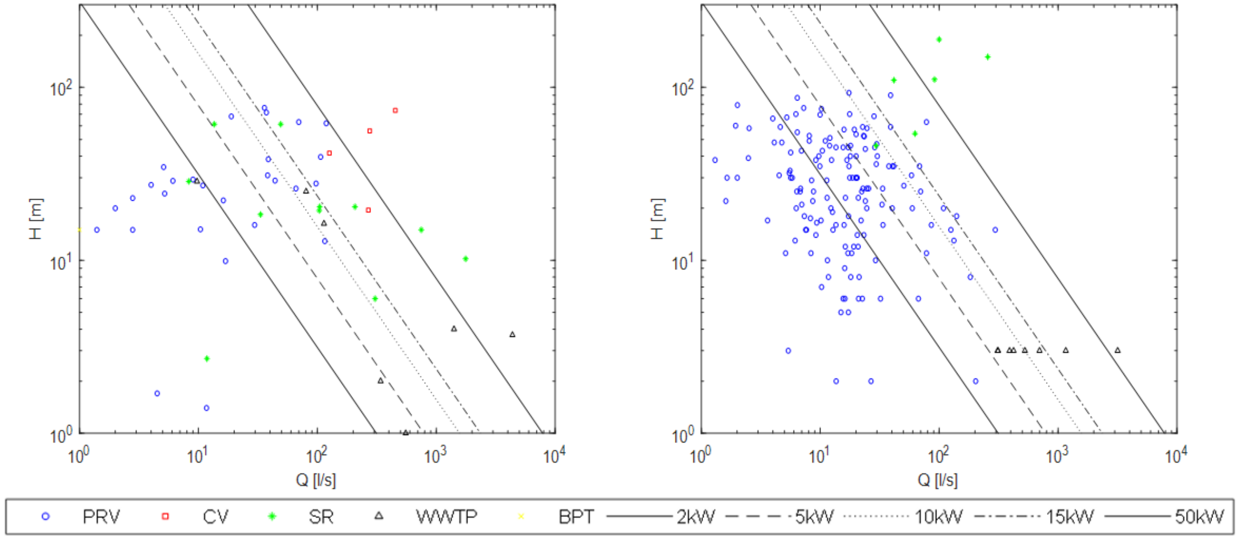
Site classification		No. of sites				Energy recovery (kW)
		5–10 kW	10–15 kW	>15 kW	Total	
Ireland	SRV	1	3	4	8	276
	PRV[a]	5	1	10	16	585
	WWTP	0	2	2	4	164
Wales	SRV	1	0	5	6	490
	PRV	25	8	5	38	397
	WWTP	4	2	2	8	134
Total	SRV	2	3	9	14	766
	PRV[a]	30	9	15	54	982
	WWTP	4	4	4	12	298

[a] Four control valves included within PRV group in Ireland.

Distribution of the potential for energy recovery

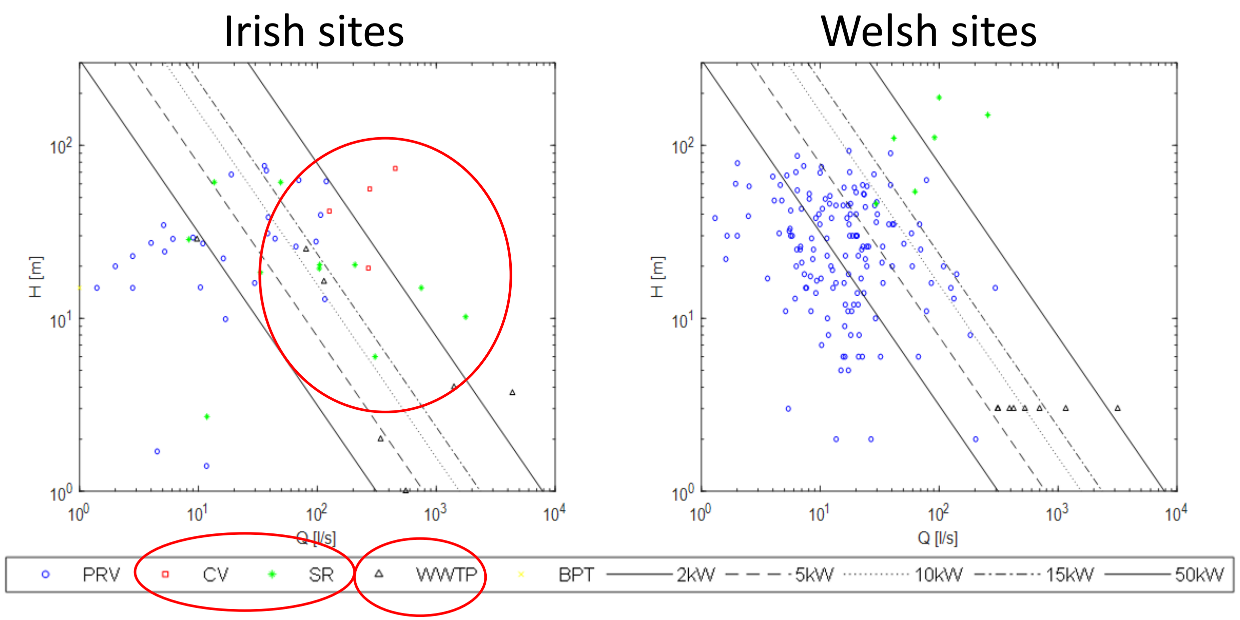
Irish sites

Welsh sites



RESULTS (Population)

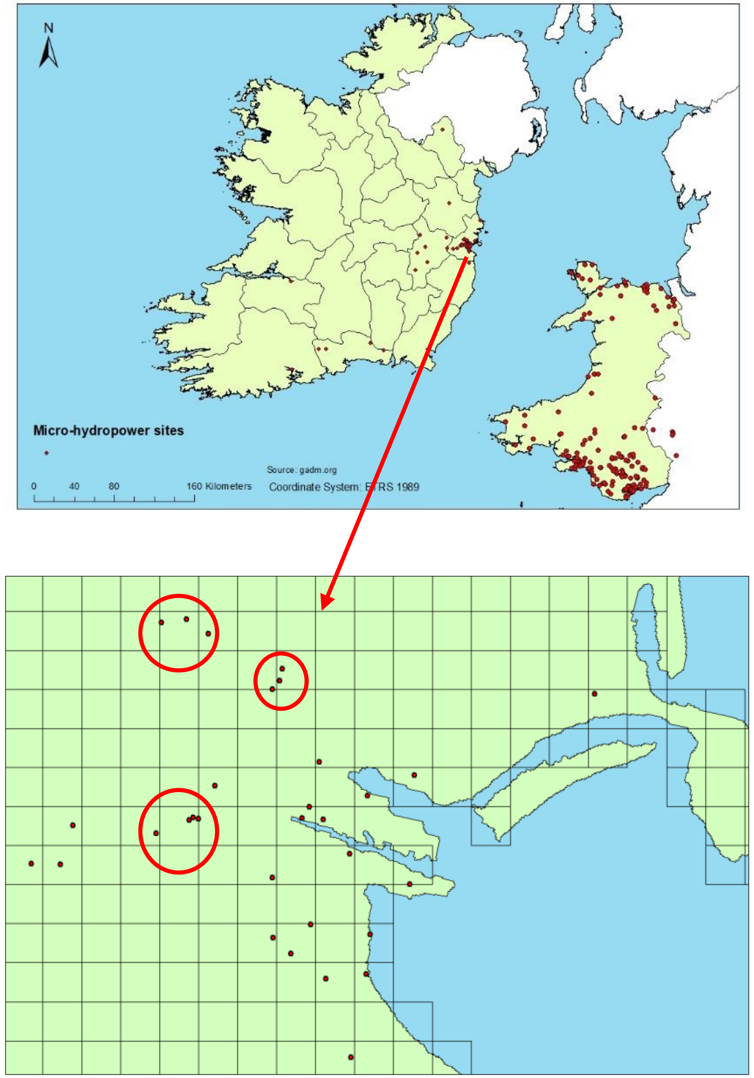
Distribution of the potential for energy recovery



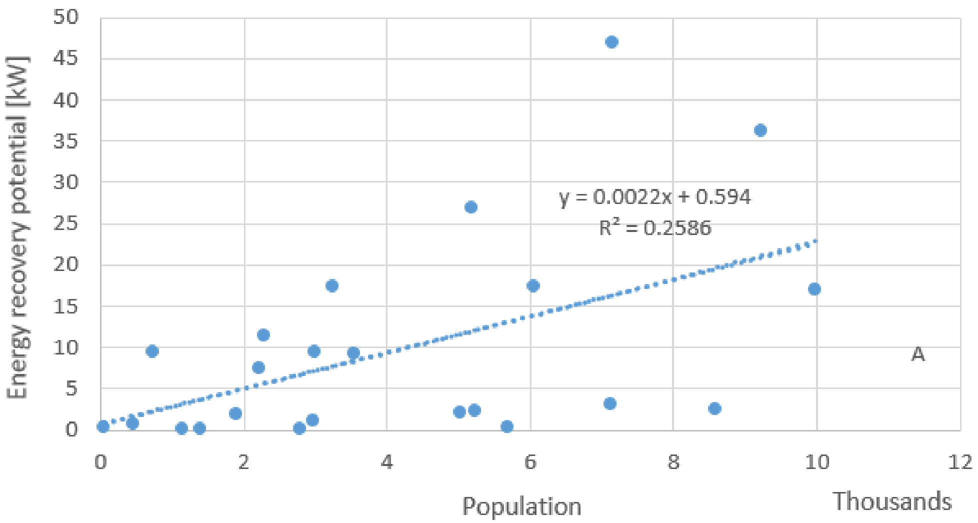
alternative	Filters applied	R squared							
		Ireland				Wales			
		1km	3km	5km	No. of sites	1km	3km	5km	No. of sites
0	none	0.063	0.038	0.023	51	0.01	0.011	0.009	165
1	type≠WWTP	0.098	0.062	0.035	44	0.01	0.011	0.009	158
2	type=PRV	0.214	0.193	0.148	28	0.002	0.003	0.008	152
3	type=PRV & County=Dublin/Cardiff	0.183	0.161	0.118	26	0.016	3E-04	0.044	15
4	type=PRV & Power<15kW	0.003	0.019	0.061	22	0.015	0.014	0.022	147
5	type=PRV & 2<Power<50kW	0.216	0.185	0.157	14	0.004	0.001	2E-04	89

Linear Least – Squares Regression analysis between the energy recovery potential of the sites and population inside buffers

RESULTS (Population)



Correlation between Energy recovery potential of sites and population inside 1x1 km^2 grid cells



RESULTS (Topography)

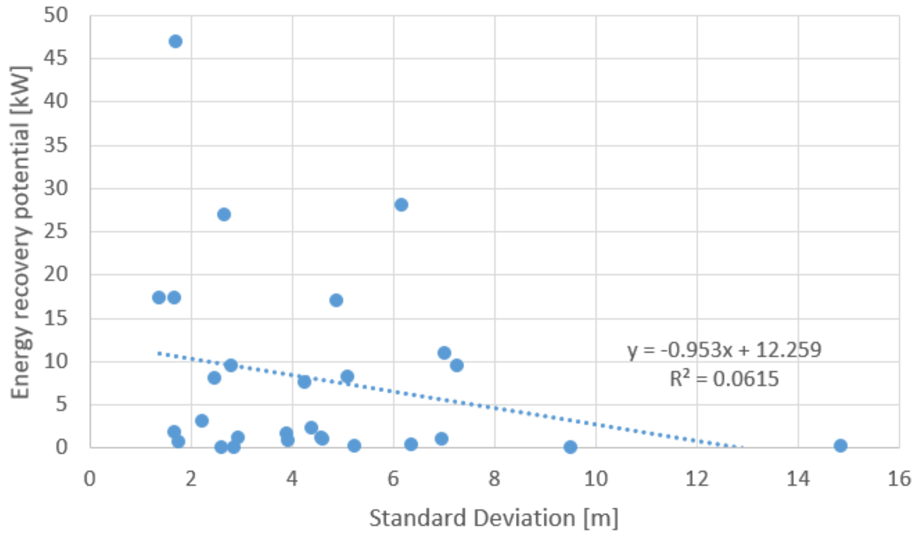
Linear Least-Squares Regression analysis between the energy recovery potential of the sites and terrain variability variables

Filtering did not improve the R^2

	alternative	Filters applied	Ireland				No. of sites	Wales				No. of sites
			0.5km	1km	3km	5km		0.5km	1km	3km	5km	
SD of DEM buffers	0	none	0.011	0.002	0.007	0.001	51	0.026	0.040	0.045	0.037	186
	1	type=PRV	0.057	0.006	0.045	0.042	28	0.004	0.004	0.006	0.014	173
	2	type=PRV & Power<15kW	0.000	0.003	0.027	0.039	22	0.001	0.001	0.001	0.000	168
	3	type=PRV & 2<Power<50kW	0.005	0.060	0.000	0.000	14	0.002	0.000	0.001	0.013	81
	4	Power<50	0.003	0.008	0.007	0.007	46	0.002	0.003	0.007	0.010	182
Slope	0	none	0.069				51	0.044				186
	1	PRV	0.058				28	0.000				173
	2	P<50	0.044				46	0.000				182
	3	PRV & 2<P<50	0.001				14	0.005				81

Negative slope of regression lines

$$\frac{dPower}{dPopulation} > 0; \quad \frac{dPower}{dTerrain\ variablitity} > 0$$



Nonlinear regression models were considered, but the datasets were too scattered and did not show any nonlinear trends!

CONCLUSIONS

Spatial regression analysis was performed to assess is there a correlation of energy recovery potential and population and terrain variablility variables.

Results showed that there is no significant correlation (the best R^2=0.26), and that the variables used cannot explain the variations in the potential.

Previous extrapolation of the MHP potential in the literature by population could therefore be erroneous!

Future research

- Finding new independent variables which will be able to explain variations of the MHP potential.
- Change the scale on which the correlation is assessed (e.g. Correlation of a sum of the potential of a cluster of sites and the geographical data of the whole area which is covered by the cluster.
- Exploring different approaches.

Thank you for your attention!

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