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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INTRODUCTION

- Water Pipe Networks = Water Supply Networks + Wastewater Networks
- 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 (MHP)

Water Supply Networks (WSNs)

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

INTRODUCTION

• Water Pipe Networks = Water Supply Networks + Wastewater Networks
• 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

b) Upstream sewage water micro-hydropower plant

Source: Bousquet et al. 2017
INTRODUCTION

• Barriers which prevent exploitation
  • Technical
    • Variations of flow and pressure
  • Pressure control
  • Conventional turbines cannot be scaled down in economically viable way
  • Lack of performance curves for Pump-As-Turbines (PATs)

Source: Carravetta et al. 2012

Source: Binama et al. 2017
INTRODUCTION

• Barriers which prevent exploitation
  • Non-technical
    • Lack of incentives
  • Lack of awareness about the existing resource available
  • Lack of 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

$$\text{Power} = \rho g Q H \eta \ [\text{KW}] \quad \eta = 0.65$$
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 \( \rightarrow Power = \rho g Q H \eta \) [kW]

• Challenge: Finding independent variables which would explain variation of the potential without having the networks to which the sites belong

Source: http://www.integrated-assessment.eu
SPATIAL REGRESSION ANALYSIS (Population)

Power = $\rho g \frac{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)

Type and Resolution of extracted data (variables):
- Population inside the buffers: 1,3 and 5 km
- 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)

- \( \text{Power} = \rho g Q H \eta \) [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. \( I_{Net} = \frac{H_{Tanks,\text{max}} - Z_{\text{min}}}{L_{Tot,Net}/N_{Tanks}} \)

\( I_{Net} \), 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

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

<table>
<thead>
<tr>
<th>Site classification</th>
<th>No. of sites</th>
<th>5–10 kW</th>
<th>10–15 kW</th>
<th>&gt;15 kW</th>
<th>Total</th>
<th>Energy recovery (kW)</th>
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<td>4</td>
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<td>Wales</td>
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</tr>
</tbody>
</table>

* Four control valves included within PRV group in Ireland.

Distribution of the potential for energy recovery
RESULTS (Population)

Distribution of the potential for energy recovery

![Irish sites](image1)
![Welsh sites](image2)

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

<table>
<thead>
<tr>
<th>alternative</th>
<th>Filters applied</th>
<th>R squared</th>
<th>Ireland</th>
<th>Wales</th>
<th>No. of sites</th>
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<tbody>
<tr>
<td>0</td>
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<td>0.063</td>
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</table>
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 $R^2$

<table>
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<th>Alternative</th>
<th>Filters applied</th>
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<th></th>
<th></th>
<th>Wales</th>
<th>No. of sites</th>
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<td>3km</td>
<td>5km</td>
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<td>1km</td>
<td>3km</td>
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<tr>
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<td>0.003</td>
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<td>0.002</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Slope

- $\frac{d\text{Power}}{d\text{Population}} > 0$; $\frac{d\text{Power}}{d\text{Terrain variability}} > 0$

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 variability 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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