Estimating the costs of improving waste water treatment in catchments draining into the Baltic



- Jim Smart, Berit Hasler, Mikolaj Czajkowski, Erik Smedberg, Anders Fonnesbech-Wulff and Mette Termansen

Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems
Stockholm University
Baltic Nest Institute

Cost-effective reduction of nitrogen and phosphorus pollution in the Baltic

- Find which combination of measures, in which locations, provides the most cost-effective way of achieving targets for reduced N & P loadings in 9 sea basins in the Baltic
- Aim to meet HELCOM targets for water quality in the 9 sea basins around the Baltic

N & P load reduction measures

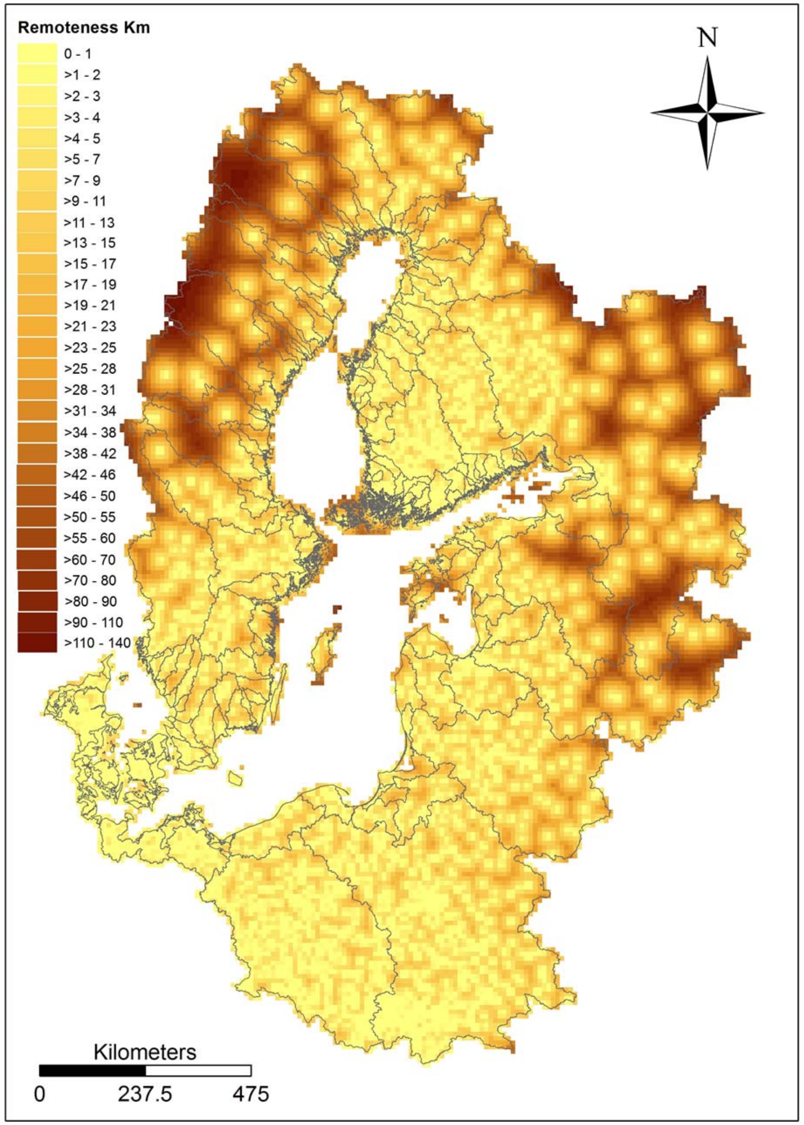
- N & P reduction measures considered
  - reduce application of fertiliser and manure on farmland
  - reduce livestock numbers
  - increase connection to and/or improve effectiveness of waste water treatment (WWT)
  - restore and/or construct wetlands to ‘trap’ N & P runoff
  - sow catch crops under spring cereals to ‘catch’ N & P runoff
  - reduce atmospheric deposition of NOx
- Optimisation problem – which of these measures should be carried out ? where ? and to what extent to produce the ‘least cost’ solution to achieve N & P load targets ?
- Optimisation operates on a catchment scale (24 catchments BNI) and on a 10 x 10km grid cell scale (RECOCA)

What would we like to know about WWT ?

- **How many** households (or PEs) could be provided with improved WWT in ….
  - Grenaa, Uppsala, Turku, Tallinn, Krakow, ….
- How much would N & P **loads** in the relevant sea basin **reduce** if person was connected to improved WWT ?
- How much would it **cost** to provide an improved level of WWT to a person (PE) in ….
  - Grenaa, Uppsala, Turku, Tallinn, Krakow, ….

Capacity for improvement ?

- National scale data on total population connected to 1, 2, 3-level WWT
- Incomplete data on location and size of existing WWTPs
- GIS-calculation of remoteness: distance from WWTP or town > 10,000
- Assume population connected to WWT in order of ascending remoteness
- Predict location of remaining unconnected population at 10 x 10km resolution – aggregate up to sub-catchments



Effect of improvement

- Use standard N & P removal percentages for 1, 2, 3-level WWT at the WWTP location itself
- Use newly calculated, site-specific surface-water retention values to estimate the effective reduction in nutrient loadings into the relevant sea basin
- Capacity and effectiveness now addressed ….
- What is the **cost** of connecting and/or treating waste from one more ’treatable household’ in Grenaa, Uppsala, Turku, Tallinn, Krakow ….

Capacity for improvement ?

- Some households are so remote that any form of municipal treatment is just not feasible (’not treatable’)
- For some of these treatable households septic tank + lorry tanker delivery will be the cheapest option for accessing municipal WWT, for other households mains sewer connection will be cheaper.
- What is the **cost** of connecting and/or treating waste from one more ’treatable household’ in Grenaa, Uppsala, Turku, Tallinn, Krakow ….

Cost of providing improved WWT

- Combine descriptive and behavioural ‘top-down’ economic models to make best use of available data (from Poland and Denmark)
- Estimate cost of connecting / treating one more PE at a particular location
- Models predict average cost of WWT (€/PE), driven by size of WWTP, the prices of inputs to the WWT process (labour, energy), controlling for differences in infrastructure

Cost of WWT vs. WWTP size

- Data on WWT in Poland (from Mikolaj Czajkowski: Warsaw University)
- Total and average cost of WWT from 1114 WWTPs of different capacities in Poland (mainly 2 & 3-level)
- Model: average cost of WWT varies with plant capacity

$$AC^{(\theta)} = \alpha + \beta \cdot Y^{(\lambda)}$$

Where AC denotes average cost and Y denotes plant size (m^3)
Where (θ) and (λ) denote Box-Cox transformations in which:

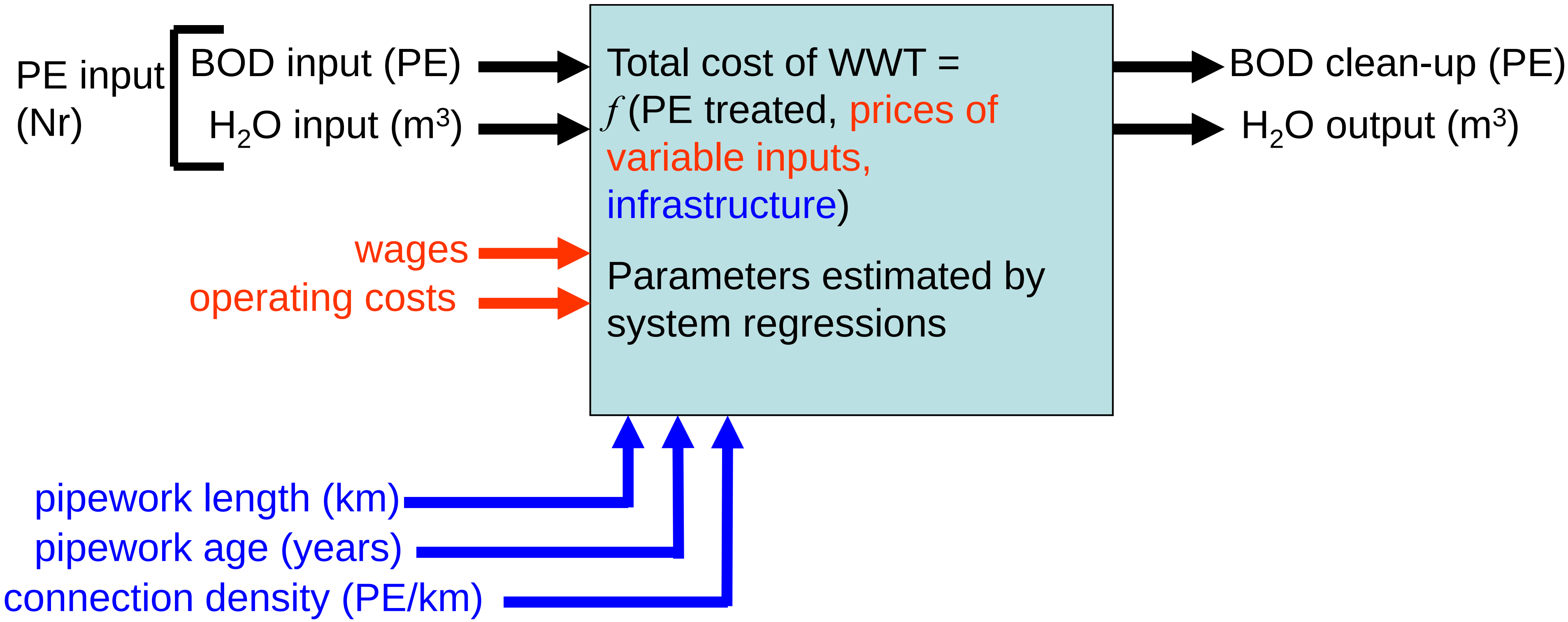
$$AC^{(\theta)} = \begin{cases} \dfrac{AC^{\theta} - 1}{\theta} \end{cases} \text{for } \theta \neq 0 \text{ or } \ln\theta \text{ for } \theta = 0$$

Parameters estimated by the Box-Cox regression model are:
θ, λ, α, β

Cost of WWT vs. WWTP size

- Model: Box-Cox form regression model, predicting average cost of WWT based on the capacity of the treatment plant
- Estimation results identify significant plant size effect on cost; good fit to observed cost data Adj R^2 >0.85
- But …. only based on Polish data. How should this cost function be applied elsewhere around the Baltic ?

Cost of WWT allowing for scale of operation, relative costs of inputs and existing infrastructure



Data from 10 Danish WWT **companies** across 3 years each operating 1 – 15 WWT plants of between 5.000PE and 500.000 PE annually. All companies operating **tertiary** treatment (almost exclusively)

Cost of WWT allowing for scale of operation, relative costs of inputs & existing infrastructure

$$\ln C = \alpha_0 + \alpha_Y \ln Y + + \frac{1}{2}\delta_{YY}(\ln Y)^2$$
$$+ \sum_j \beta_j \ln P_j + \frac{1}{2}\sum_i \sum_j \delta_{ij} \ln P_i \ln P_j$$
$$+ \gamma_Z \ln Z + \frac{1}{2}\delta_{ZZ}(\ln Z)^2$$
$$+ \sum_j \eta_{Yj} \ln Y \ln P_j + \eta_{YZ} \ln Y \ln Z + \sum_j \eta_{jZ} \ln P_j \ln Z$$

Where:
C = total annual cost of WWT,
Y = BOD cleanup (PE)[measure of scale],
P_j = input prices
Z = infrastructure (pipe network, population density etc)
$\alpha,\beta,\gamma,\delta,\eta$ terms are parameters estimated by regression

DK translog cost model results

- Good overall fit to cost data: R^2 system > 0.90
- Average cost in this translog relationship is compatible with the average cost function from Poland in how it responds to scale of operation
- Significant effect of prices of labour and O & M (energy) on total cost of providing WWT – after controlling for effect of plant size and installed infrastructure on WWT cost
- Allows **percentage change in WWT cost per percentage change in input prices** to be calculated (elasticity of cost with input price)
- Use these results to re-scale the basic Polish relationship for WWT vs plant size to other countries round the Baltic, knowing average size of WWT plants (primary, secondary or tertiary) in location modelled and variation in costs between countries

To complete the work ……

- Program WWT cost functions into BALTCOST cost minimisation optimiser at drainage basin scale … together with cost models for fertilser reduction, livestock reduction, re-constructed wetlands etc.
- Run the cost-effectiveness optimiser to determine ’least cost’ mixture of N & P reduction measures – and their spatial distribution – to achieve HELCOM targets for N & P loadings in the different Baltic sea basins

Thank you for listening


N
BB
Finland
Sweden
Norway
BS
GF
Russia
Estonia
GR
Latvia
KT
BP
Lithuania
Denmark
Belarus
DS
Germany
Poland
Ukraine
0 50100 200 300 400
Kilometers
Czech Republic