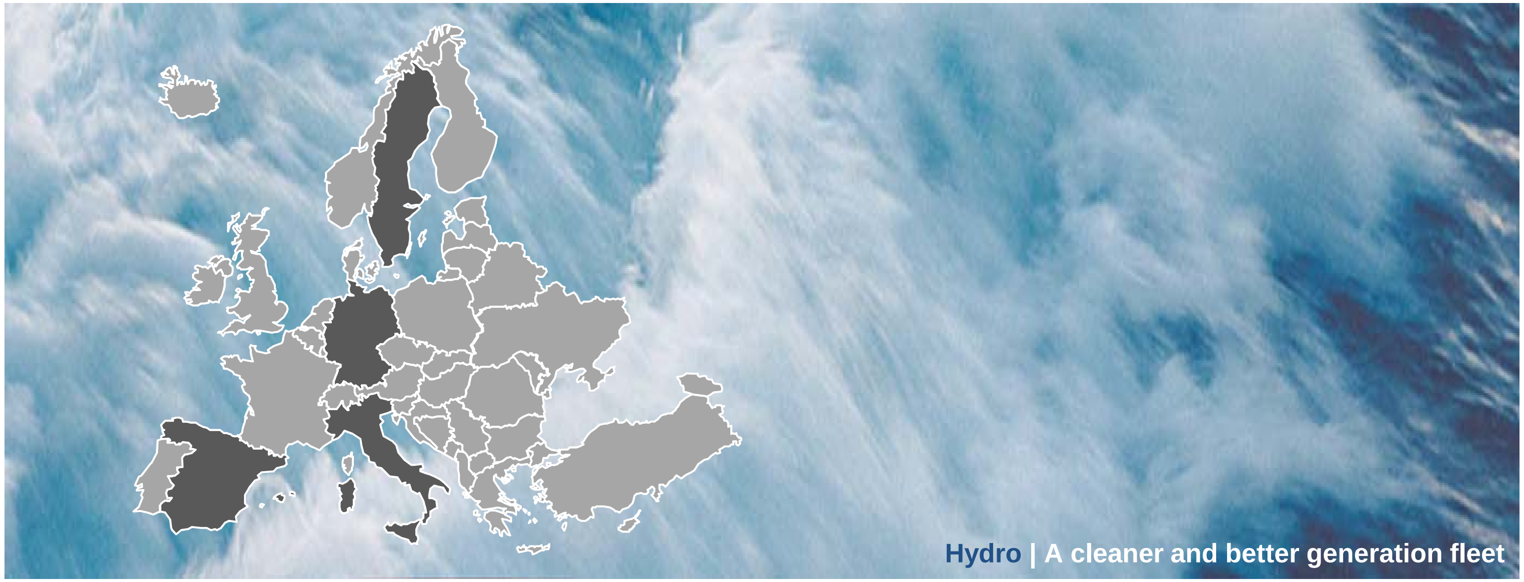


Benchmarking of Hydropower Plants

Dr. Klaus Engels | Dr. Christoph Müser | Bernhard Möstl
VGB Conference
Hamburg – September 18, 2014

Declining revenues and increasing regulatory obligations require hydro operators to focus on cost performance

Two main levers for value creation …

Revenue Increase

a) Increase of production volumes through upgrades and new build
b) Development of new ‚products'
c) Increase of energy prices

Cost Reduction

a) Decrease of O&M costs

Challenging EU market environment

- Limited growth opportunities due to regulatory hurdles
- Uncertain market developments
- Declining market prices

Hydropower Benchmarking

- Identification of performance differences
- Feedback on absolute and relative cost position compared to others

Benchmarking hydroelectric power plants is a valuable method to provide insights in O&M cost performance

Situation and Challenge

- Hydro plant operators are interested in gaining insights in O&M cost performance of their assets
- A benchmark might help, **however**, **simple KPIs such as EUR/MWh or EUR/MW are not sufficient**
  - Individual plants have different cost structures
  - Each plant has different characteristics influencing O&M cost such as size, capacity,…

Key Question ?

What aspects does a benchmark need to consider in order to provide **valuable information** for plant operators and point out weak-performing plants?

There are multiple benefits for hydropower operators when participating in an external benchmarking

Transparency

- Collection of cost data according to EN 13306[1]
- Collection of technical parameters

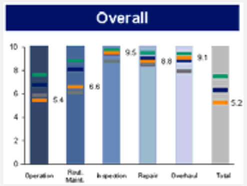
A significant step towards data transparency in line with internal standards was observed

Cost in kEUR/a		Internal	External	Total
Modification (annualized)	Add. info.	0	103	103
Overhaul (annualized)	Add. info.	0	161	161
Overhaul (annual)	In scope cost data	19	6	25
Repair	In scope cost data	20	12	32
Inspection	In scope cost data	32	15	48
Routine Maintenance	In scope cost data	81	61	142
Operation	In scope cost data	98	72	170
TOTAL		250	431	681

Challenge

- Cost normalization allows for a fair comparison of the O&M cost with hundreds of hydropower plants

The project provided detailed insights in O&M cost structure and cost drivers



Improvement

- A main outcome of the project is the cost gap to reach Top Quartile performance on plant and cost category[1] level

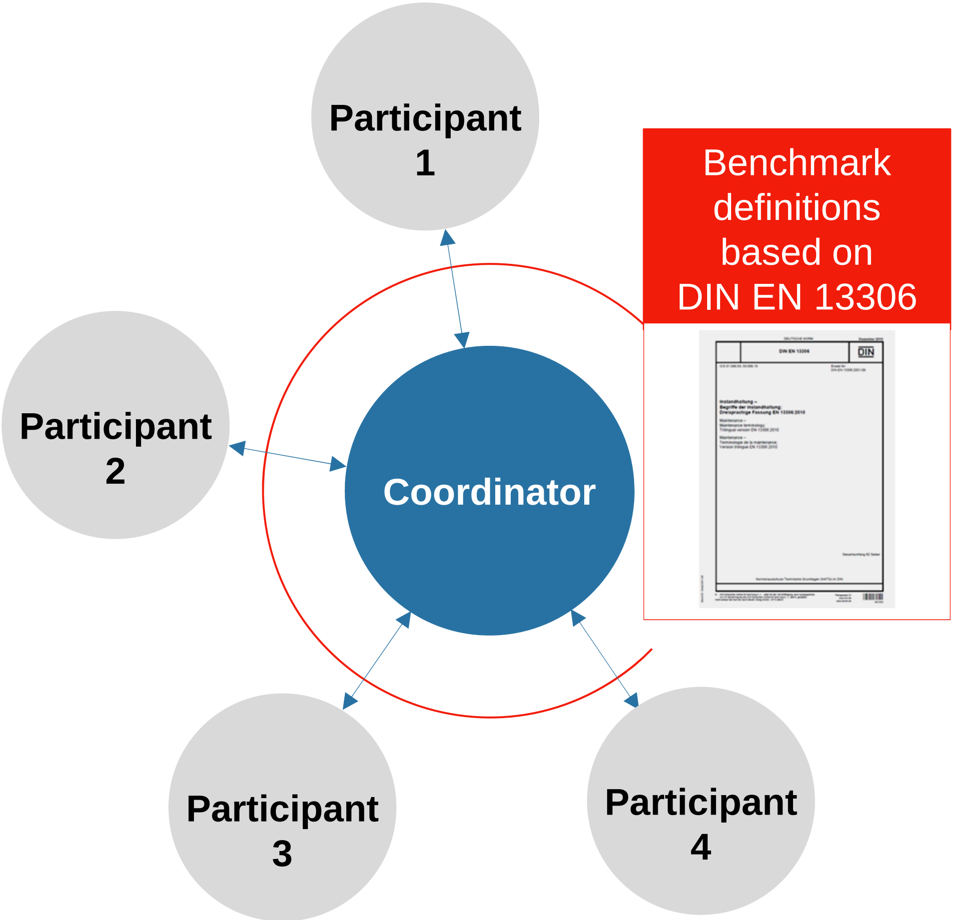
Results will facilitate identification of improvement levers to reach Top Quartile cost performance

Conclusion

- Cost performance of **Power Plant** within overall mid 50%
- To reach the top quartile in all of the clusters, indicative cost gap amounts from 15 kEUR to 108 kEUR
- Poor cost performance in Routine Maintenance and Inspection
- Average cost performance in Operation, Repair and Overhaul

1) Operation, Routine Maintenance, Inspection, Repair, Overhaul, Modification

A high quality database and a neutral coordination are fundamental prerequisites to perform the benchmarking



Creation of KIP Database

- Suggestions for possible KIPs[1] and their influence **by consultant and professionals**
- Agreement and usage of **consistent definitions** for KIPs and O&M cost types amongst all participants according to DIN EN
- Consideration of **all potential KIPs** (22) for all participating plants
- Consideration of 5 (+2)[2] cost types
- Consolidation of data from participants in a database via questionnaire by coordinator

1) Key influencing parameters
2) Operation, routine maintenance, inspection, repair, overhaul (annual) have been assessed, modification (annualized) and overhaul (annualized) have been recorded but have not been included in benchmark

Non-influenceable cost drivers need to be identified, quantified and their cost influence has to be "neutralized"

A good benchmark methodology …

… identifies non-influencable cost drivers

- Identification of all cost drivers (KIPs[1]) for all O&M cost types which
  - **drive O&M** cost differences between plants
  - **cannot be** controlled or **influenced** by staff

… quantifies and "neutralizes" influence

- Quantification of KIPs' influence with regard to magnitude and type (linear, square-root,…)
- "Neutralizing" influence by normalizing costs

…compares performance

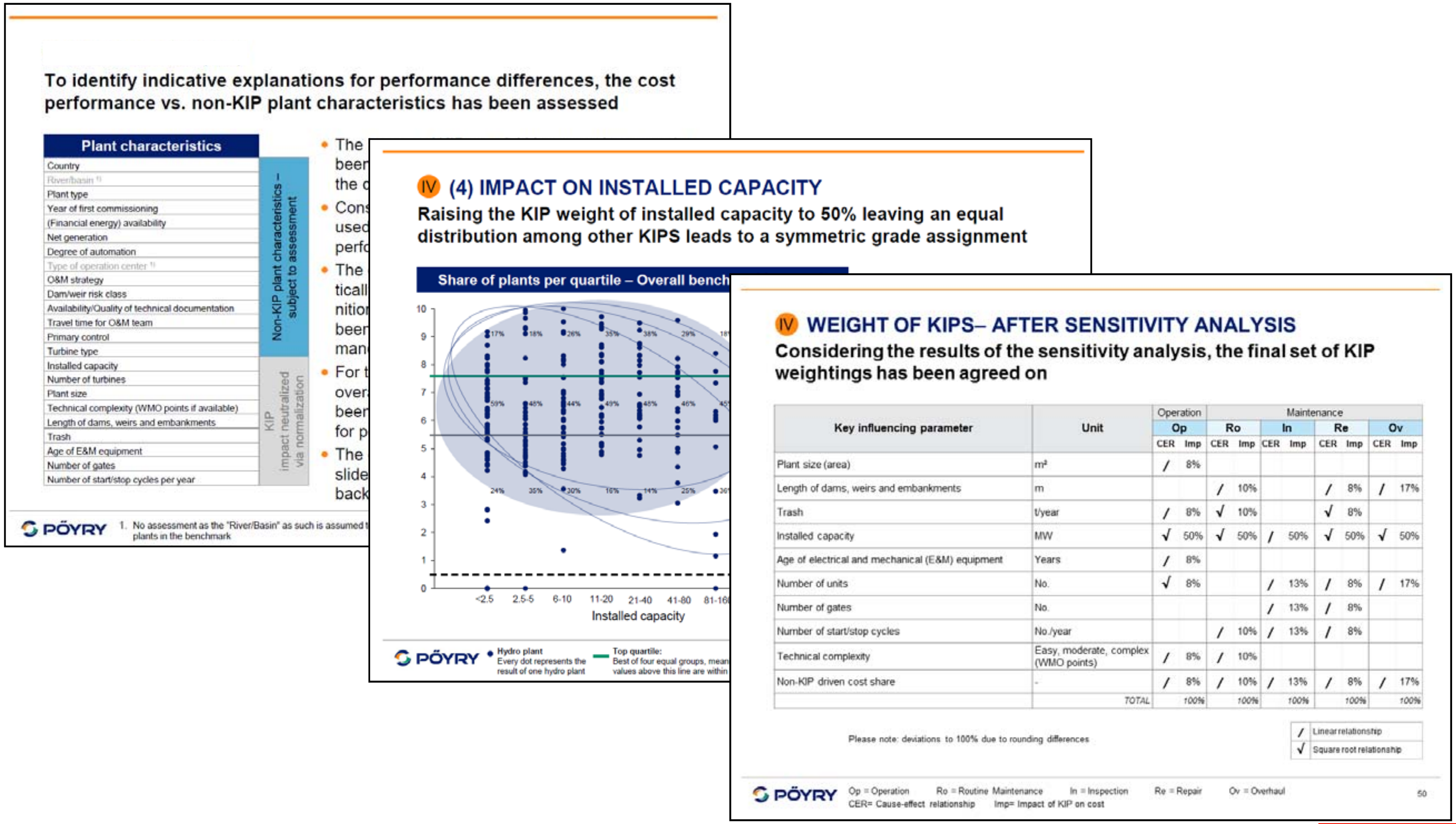
- Calculation and grading of "normalized" cost allows to directly compare "pure" performance of different plants
- Visualization of differences in performance

… creates value

- Proper interpretation of performance
- Calculation of target cost for plants to reach top quartile
- Deriving recommendations

1) Key influencing parameters

The O&M cost comparability of different hydropower plants was ensured by comprehensive cost driver analyses



Key influencing parameter	Unit	Operation		Maintenance							
		Op		Ro		In		Re		Ov	
		CER	Imp	CER	Imp	CER	Imp	CER	Imp	CER	Imp
Plant size (area)	m²	/	8%								
Length of dams, weirs and embankments	m			/	10%			/	8%	/	17%
Trash	t/year	/	8%	√	10%			√	8%		
Installed capacity	MW	√	50%	√	50%	/	50%	√	50%	√	50%
Age of electrical and mechanical (E&M) equipment	Years	/	8%								
Number of units	No.	√	8%			/	13%	/	8%	/	17%
Number of gates	No.					/	13%	/	8%		
Number of start/stop cycles	No./year			/	10%	/	13%	/	8%		
Technical complexity	Easy, moderate, complex (WMO points)	/	8%	/	10%						
Non-KIP driven cost share	-	/	8%	/	10%	/	13%	/	8%	/	17%
	TOTAL		100%		100%		100%		100%		100%

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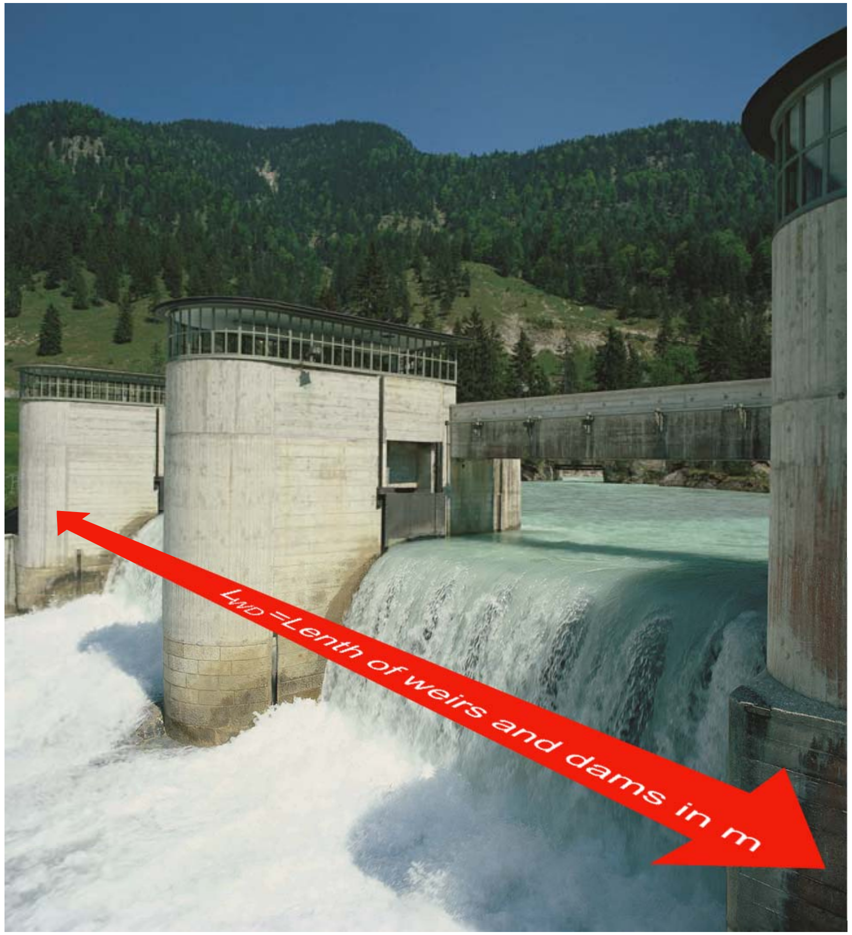
By calculating „**N**ormalized **C**ost **U**nits“, the influence of KIPs has been „neutralized“ resulting in comparable costs

Calculation of „Normalized cost units“ (**NCU**) **which can be compared** for all different plants by dividing O&M-Costs by influence of each KIP and its weight:

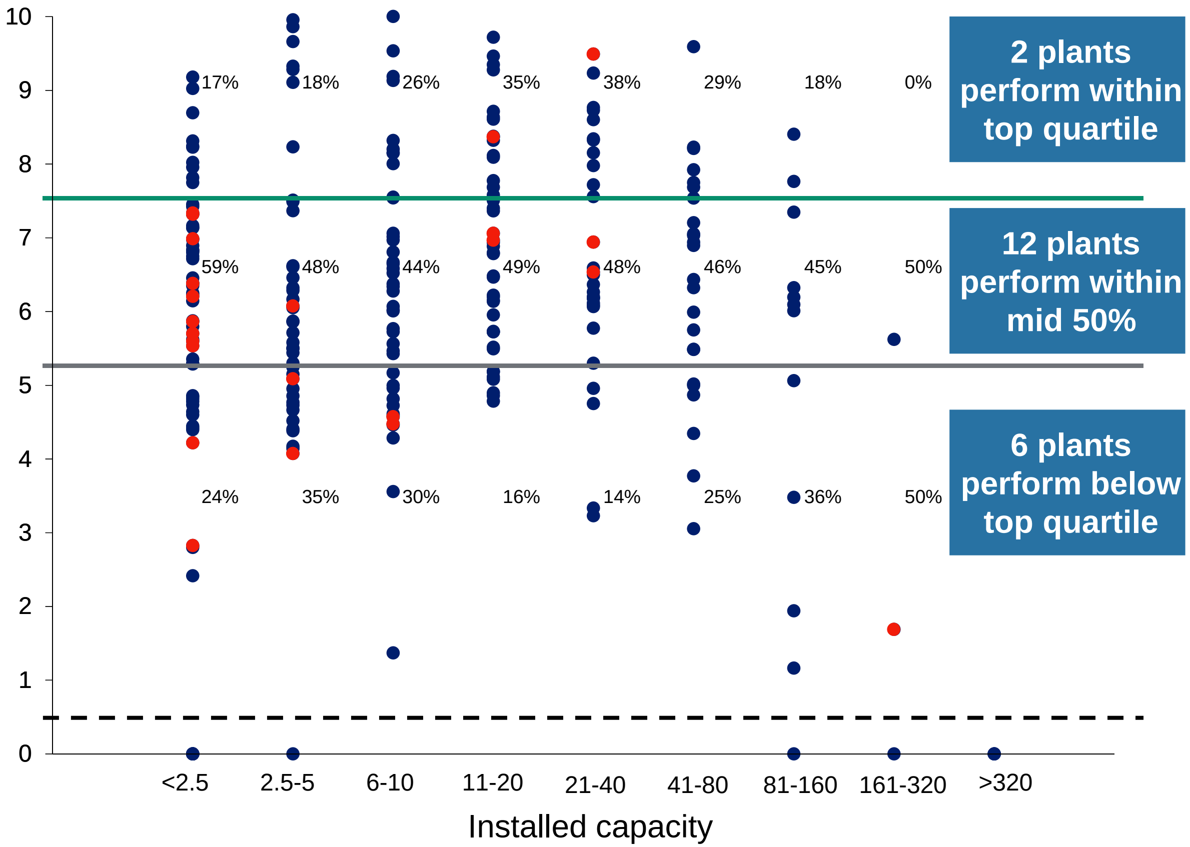
$$\boldsymbol{NCU_{OP}} = \frac{\boldsymbol{Cost_{OP}}}{\left((\boldsymbol{f}(LWD) * \boldsymbol{W}(LWD)) + \ldots\right)}$$

- $\mathrm{Cost_{OP}}$: Actual Cost for Operation of specific plant
- $f(LWD)$: Function of the KIP „Length of weirs and dams” explaining the type influence on Operation cost
- $w(LWD)$: Weight of KIP „Length of weirs and dams” compared to other KIPs as result of sensitivity analysis
- $+ \cdots$: () for **other identified KIPs**



Scatter plots have been used to identify performance patterns of benchmarked plants

Share of plants per quartile – Overall benchmarking result



Hydro plant Every dot represents the result of one hydro plant

Client X plant

Top quartile: Best of four equal groups, meaning that values above this line are within the top 25%

Low quartile: Worst of four equal groups, meaning that values below this line are within the low 25%

Outliers: Plants below this line are not included in grading due to distorting reasons

- Ranking of all plants (Client X's plants in red) after normalization
- Total O&M (NCU) cost compared to all plants clustered by installed capacity
- Overall performance of Client X's plants is below average
  - 2 plants in top quartile
  - 18 plants perform below top quartile

Note: Scatter plot reflects actual results of benchmark; Selection of plants has been done randomly for visualization purposes

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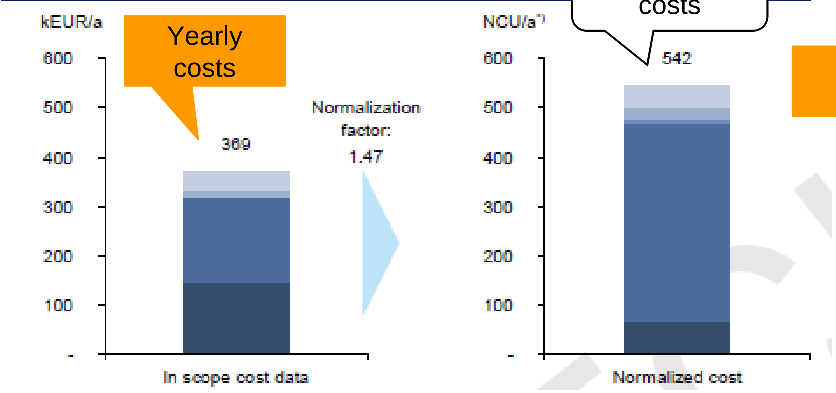
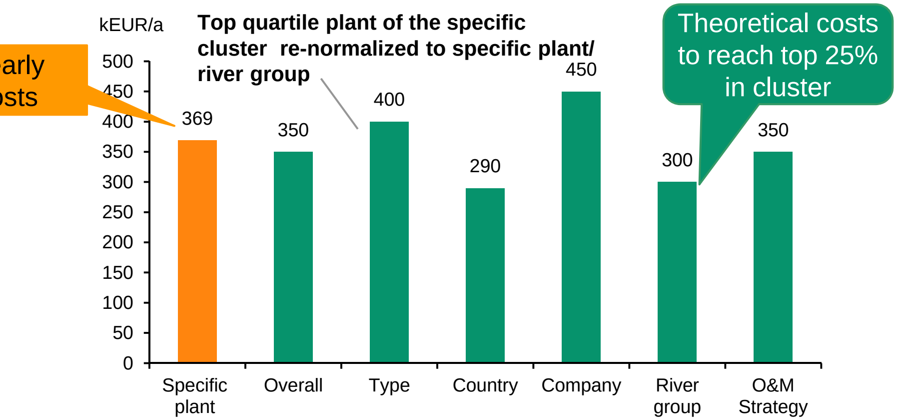
Comparison – different diagrams are used for the depiction of the plant specific benchmarking results

Annual O&M cost



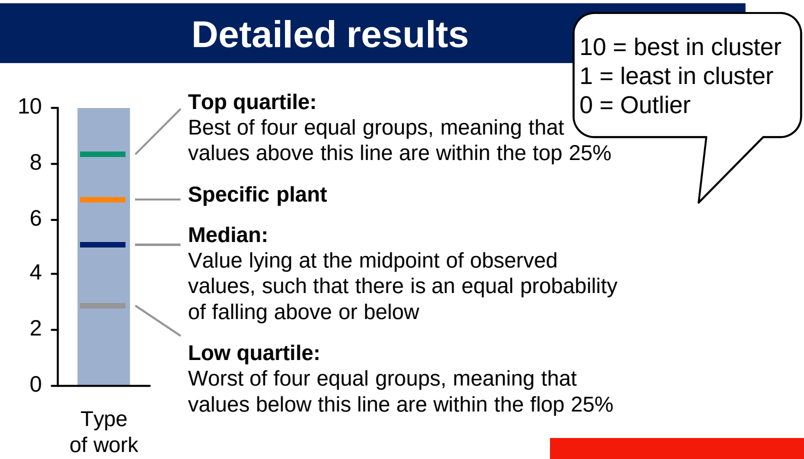
Comparisons against top quartile



Conclusions

- Cost performance of “plant name” is within overall mid 50%
- To reach the top quartile in all of the clusters, indicative cost gap amounts from -81 kEUR to 79 kEUR

Detailed results



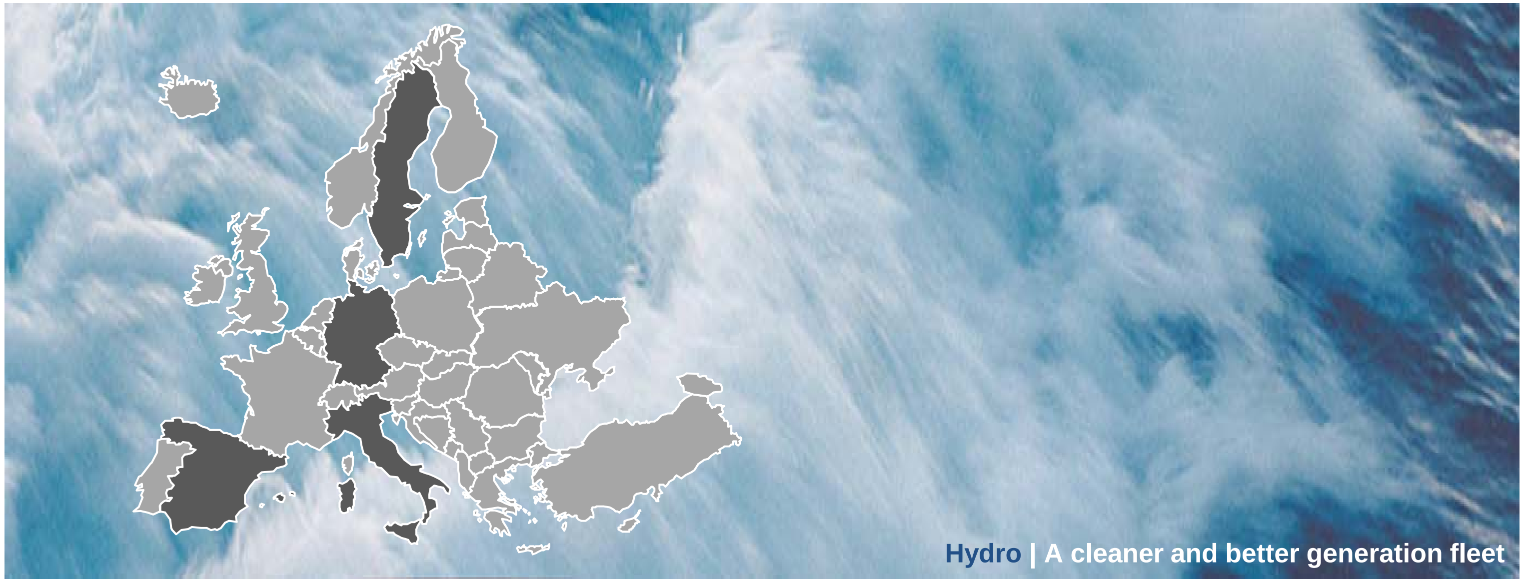
1) Normalized currency unit (NCU) in order to compare the power plants

The Hydropower Benchmarking project provided valuable insights to E.ON

- A **fair and transparent comparison** of a wide range **of different hydro plants across Europe** could be achieved by combining statistically proven methods and expert know-how.
- The **results** not only **identify** indicative **performance gaps** and **pinpoint** their **possible drivers** but also **provide insights on cause-effect relationships of O&M costs**.
- A systematic database creation and performance assessment **indicated missing information and some inconsistencies** in cost allocation at participants which can now be refined.
- The analysis **flagged up relations which were difficult to quantify beforehand** (e.g. impact of installed capacity) and did not support other common hypotheses (e.g. impact of travel time).
- **Performance differences between river groups** which cannot be explained by non-influencable factors **have been unveiled** and point out saving potentials for the future.

Pöyry and E.ON are welcoming interested hydro operators to participate in the discussion and further development of the methodology in order to continuously drive best practice and performance improvements in the hydropower industry.

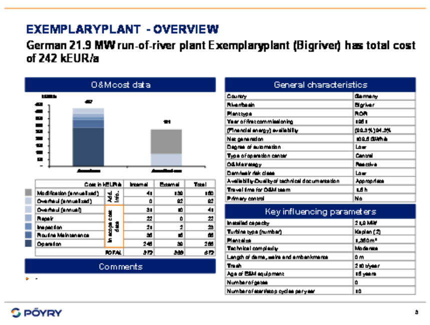
[redacted]



Backup

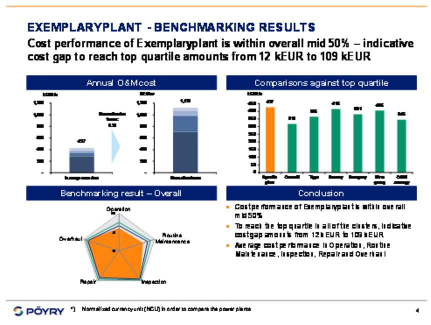
NCU allow to benchmark plant specific performance and to re-calculate target cost for low performers

Transparent data



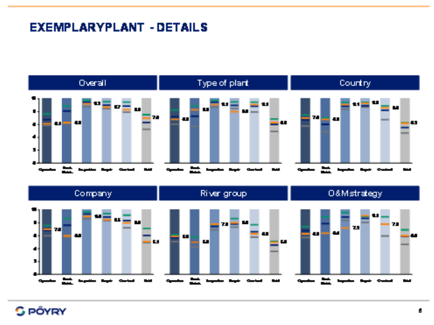
- Summary of collected information
- Key influencing parameters
- Other key characteristics
- O&M cost per type

Individual assessment



- Calculation of NCU
- Performance in the benchmark in the five O&M cost types
- Individual saving potential overall and in clusters

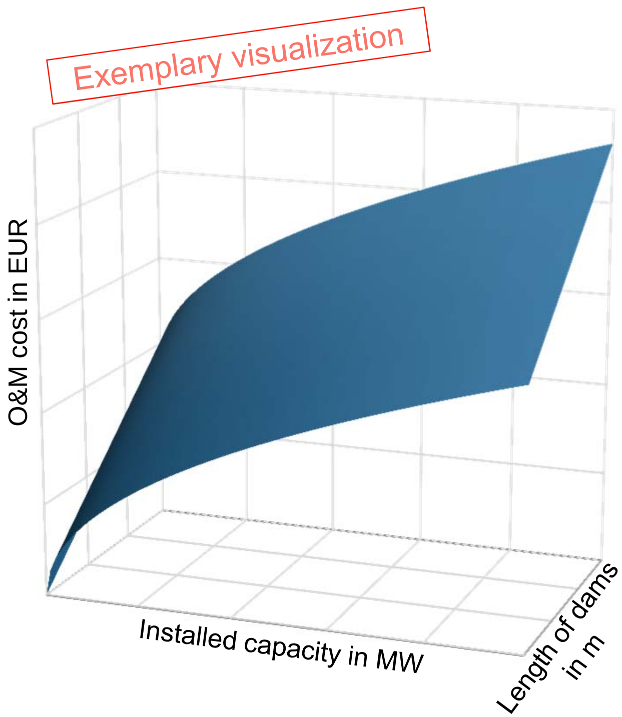
Detailed results

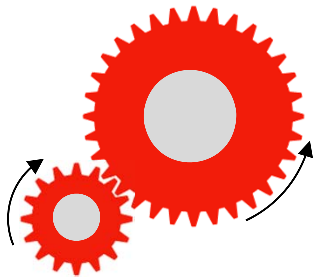


- Detailed results for all clusters and all cost types

Statistical analysis is used to evaluate non-influenceable cost drivers (1/2)

Multidimensional "Problem"	Solution	**Relevant** KIPs





Statistical Analysis (Multivariate Regression)

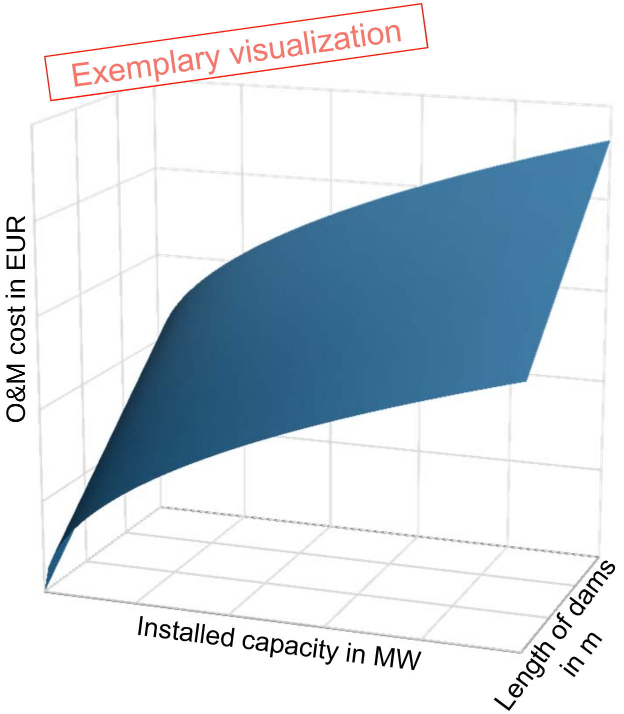
Analysis shows that only a **few factors** have an influence which is actually statistically significant[1]

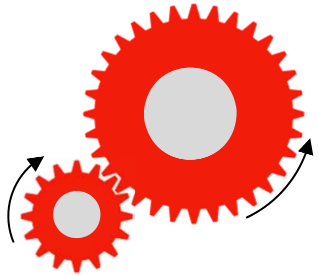
- Installed capacity
- Plant size (area)
- Length of dams, weirs and embankments
- Amount of trash
- Age of electrical and mechanical (E&M) equipment
- Number of units
- Number of gates
- Number of start/stop cycles
- Technical complexity

1) Method used: OLS; level of significance: p>5%

Statistical analysis is used to evaluate non-influenceable cost drivers (2/2)

Multidimensional "Problem"	Solution	**Non-relevant** KIPs





Statistical Analysis (Multivariate Regression)

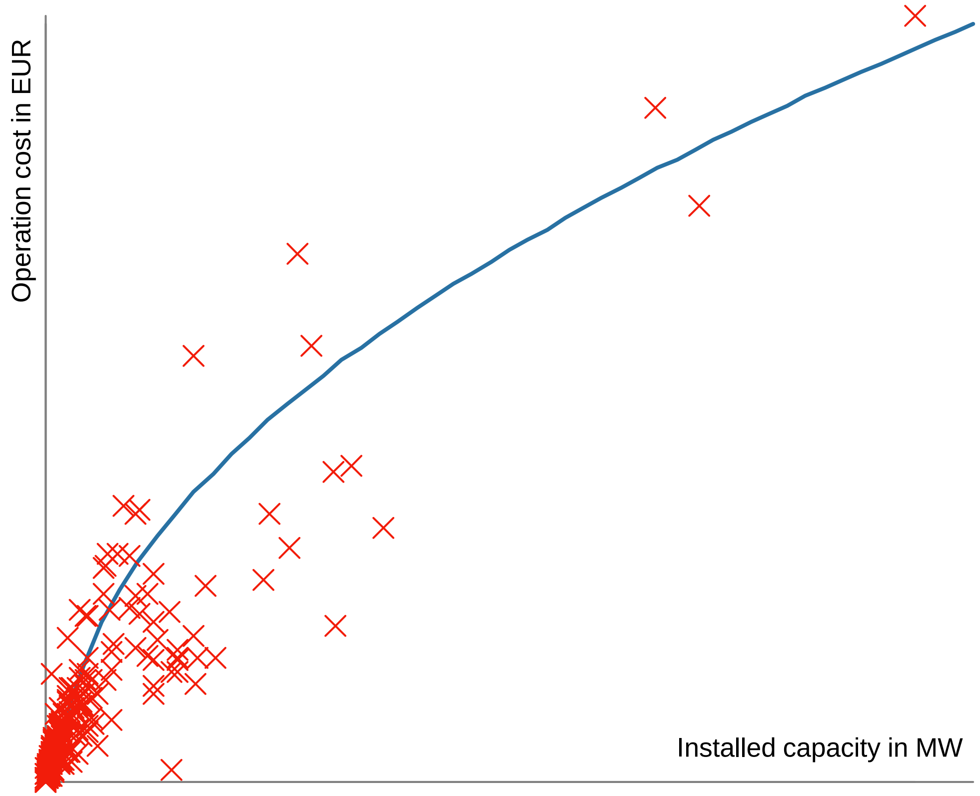
Other plant characteristics are **not** identified as **statistical relevant** key drivers for the O&M cost level:

- Financial energy availability/availability
- Level of net generation
- Dam/weir risk class
- Quality of technical documentation
- Provision of primary control
- Travel time of operation/ maintenance teams to sites

1) Method used: OLS; level of significance: p>5%

Quantification of influence is done systematically for all KIPs and all cost types

Relationship of installed capacity and O&M cost



- Assessment of type of influence (linear, square-root,…) has been done for all identified KIPs and all cost types
- Sensitivity Analysis has been used to appropriately consider the magnitude of influence of KPIs

Results show:

- **Installed capacity is the most important cost driver**
- Square root type relationship[1] between installed capacity and most O&M cost types

1) Fit-function as combined function with square root relationship for plants >20MW and linear relationship for plants <20MW; For O&M cost type „Inspection": Only linear fit-function

The Benchmarking methodology was elaborated and used for more than 260 hydropower plants

Data collection

Technical data

- Plant-specific technical parameters (KIPs[1])
- Range and weight of KIPs was determined by a comprehensive sensitivity analysis

Key influencing parameter	Unit	Operation		Maintenance							
		Op		Ro		In		Re		Ov	
		CER	Imp	CER	Imp	CER	Imp	CER	Imp	CER	Imp
Plant size (area)	m²	/	8%								
Length of dams, weirs and embankments	m			/	10%			/	8%	/	17%
Trash	t/year	/	8%	√	10%			√	8%		

Cost data

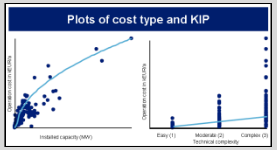
- Plant-specific internal and external costs
- Direct O&M cost only
- Distribution according to Basic Definitions

All values in kEUR	Operation						Routine Maintenance						Inspection						Repair					
	2014		2015		2016		2014		2015		2016		2014		2015		2016		2014		2015		2016	
Cost group	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext	int	ext
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Projects																								
Lump Sum Projects																								
Basic Operation & Maintenance																								
Material & Services (w/o maintenance)																								
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Projects																								
Lump Sum Projects																								
Basic Operation & Maintenance																								
Material & Services (w/o maintenance)																								

Benchmarking

Normalization factor

- Calculation of plant-specific normalization factors using KIPs[1]

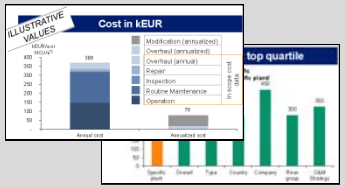


Cost normalization

- Calculation of normalized, scaled cost based on the normalization factors

Benchmarking results

- Comparison of normalized, scaled cost per power plant with more than 260 hydropower plants
- Assignment of plants to Low, Mid or Top Quartile
- Deduction of plant-specific saving potentials



1) Key Influencing Parameter