ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

HYDROPOWER DESIGN UNDER UNCERTAINTIES

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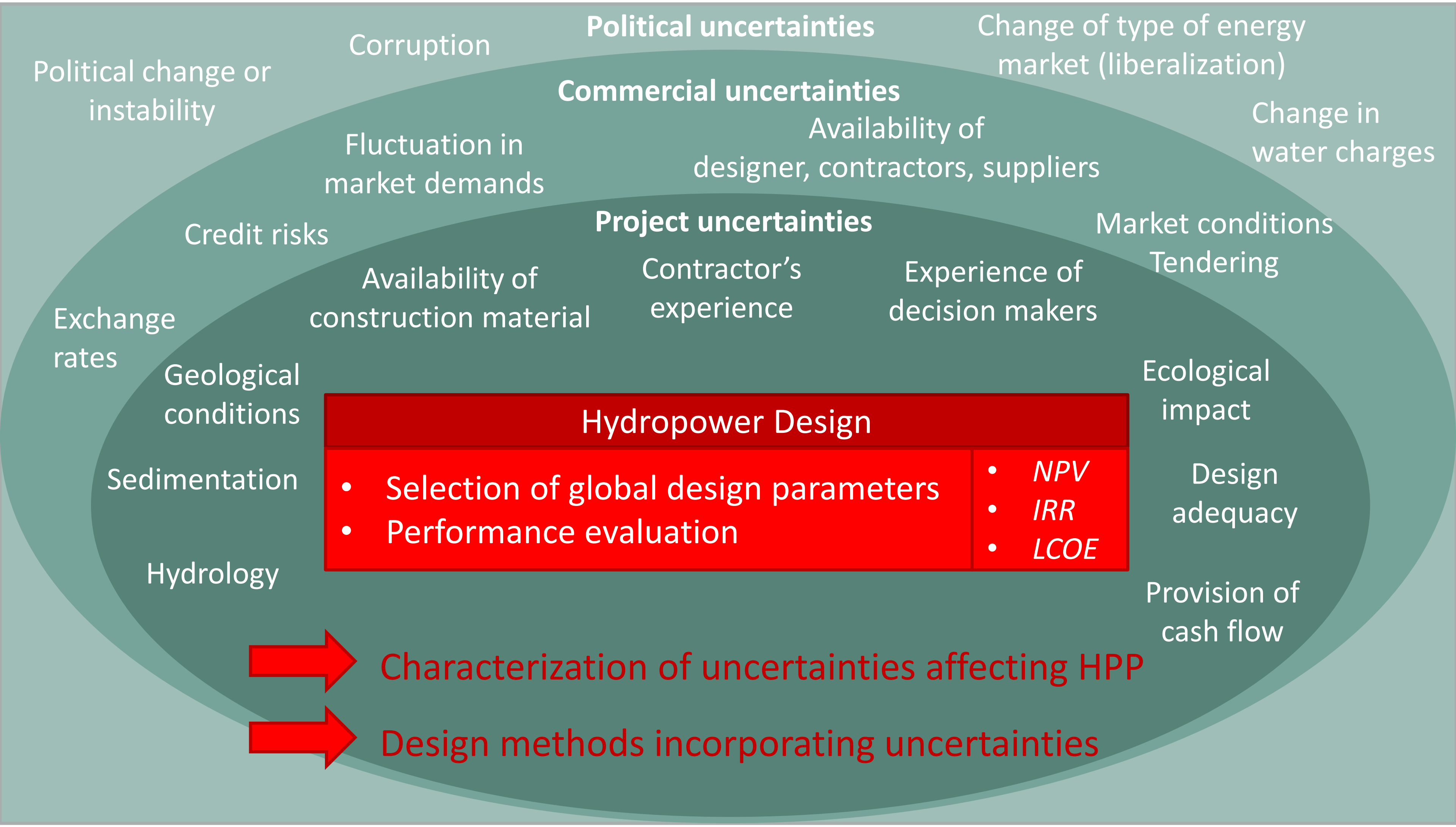
Introduction-Motivation



Structure

1.	Uncertainties of Small and Large HPP in Switzerland	• Analyses of cost overrun and production overestimation
2.	Management of Uncertainties	• Framework of new design methods for hydropower • Formulation and application of new design methods on a real hydropower project

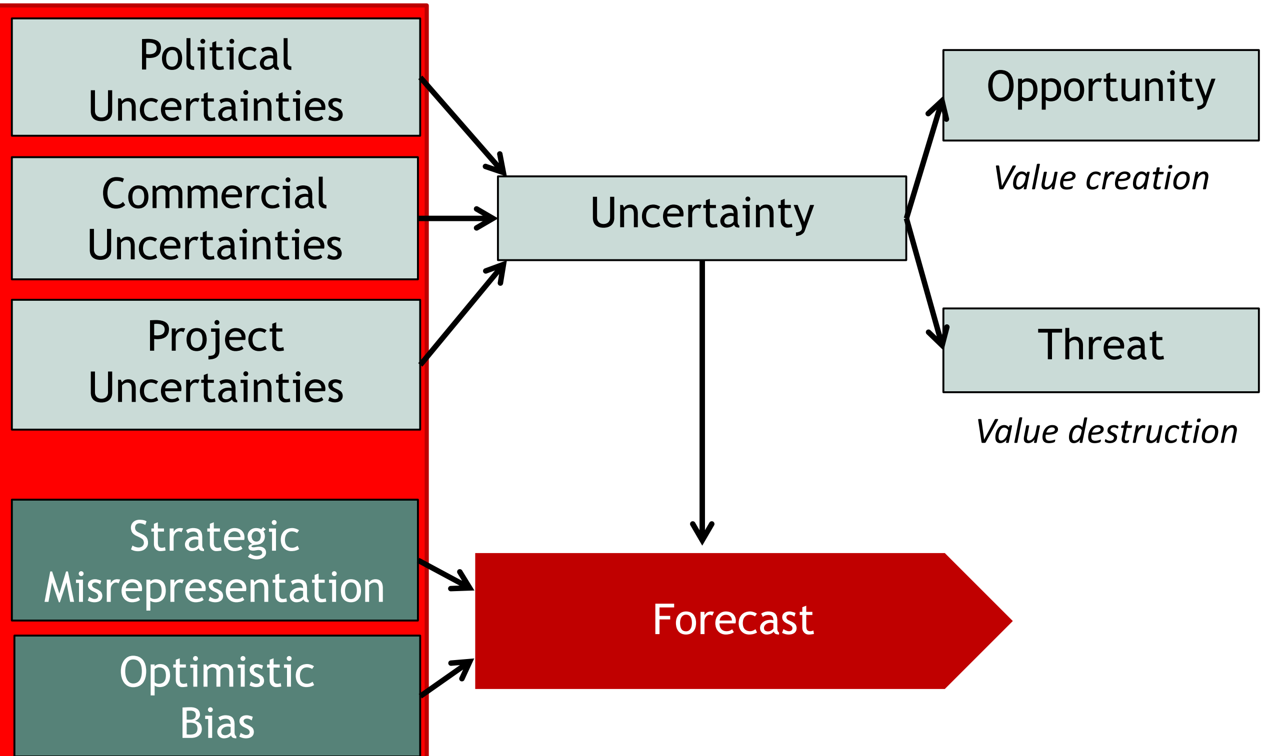
Uncertainties of Small and Large HPP

Swiss Hydropower Projects

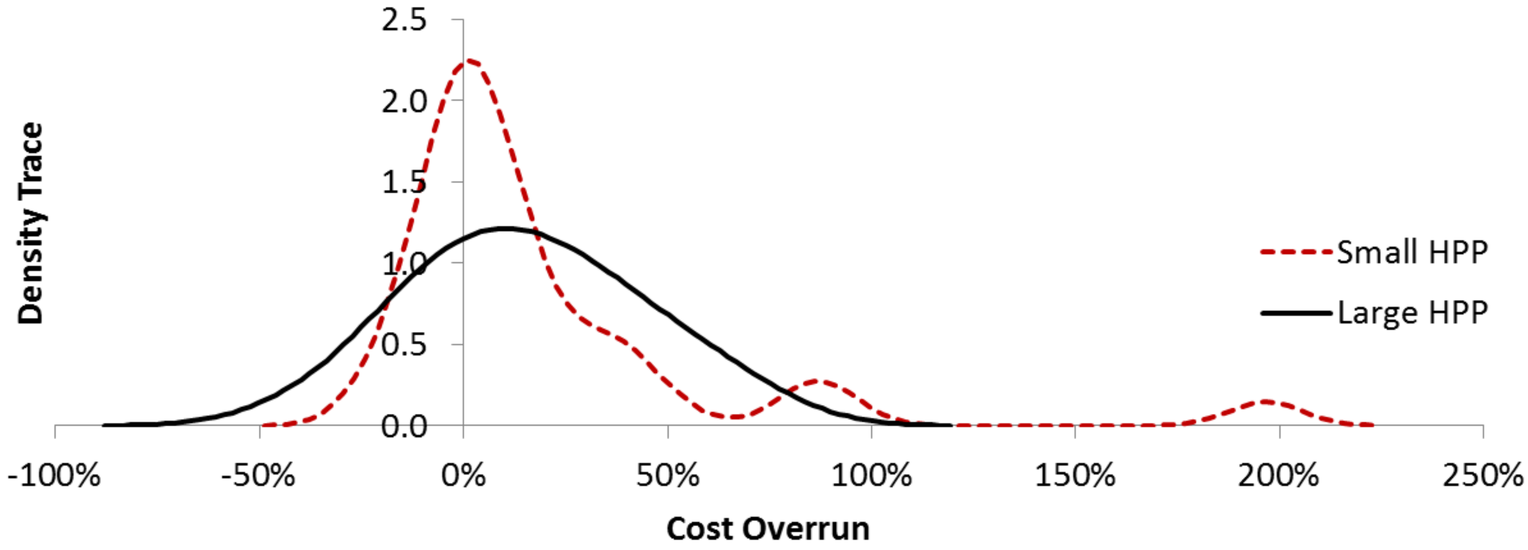
Methodology-Assessment of Uncertainties

Outside View

- Flyvbjerg (2008), Ansar et al. (2014)
- Evidence based approach
- Comparison actual and estimated outcomes
- Challenge: establishment of data base



Cost Overrun of Small & Large HPP



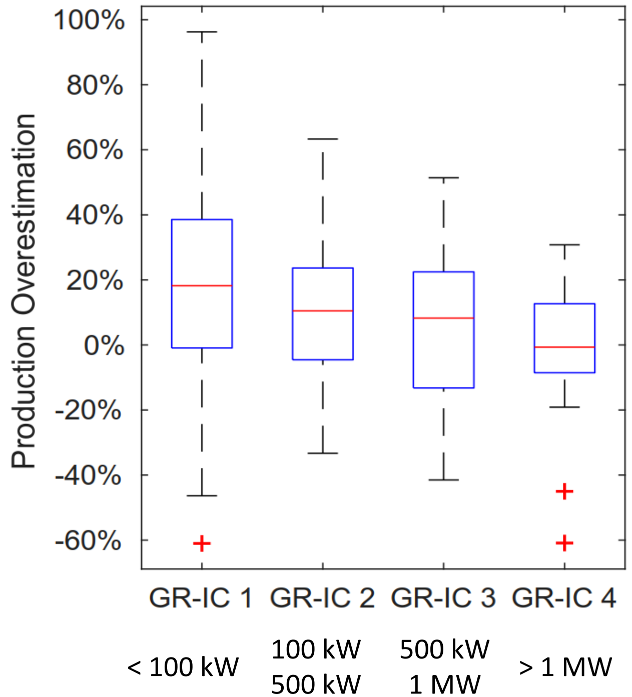
- The average cost overruns are in a similar range.
- Small projects tend to have more extreme cost overruns.
- Chance of cost overrun for Small HPP smaller than for Large HPP

	Small HPP (n= 30)	Large HPP (n = 20)
Average	18%	15%
Median	2%	15%
S.D.	42%	27%
Cost overrun	53%	67%

Energy Production of Small HPP

Small HPP: Mid-term Energy Production (n = 264)

- Energy production overestimation in 7 out of 10 projects
- Average production overestimation 14%
- Larger projects have better performance in energy production forecast



Energy Production of Small & Large HPP

- Small & Large HPP: Long-term Energy Production
- Long-term production data:
  - Small HPP production period: 43 to 54 years
  - Large HPP production period: 21 to 54 years

	Small HPP (n= 15)	Large HPP (n=24)
Total estimated production [GWh]	228	4'699
Total actual production [GWh]	217	5'086
Average production overestimation	5%	-8%
S.D.	14%	10%
Median	0%	-6%
Projects with overestimation	47%	21%
More than 20%	20%	0%

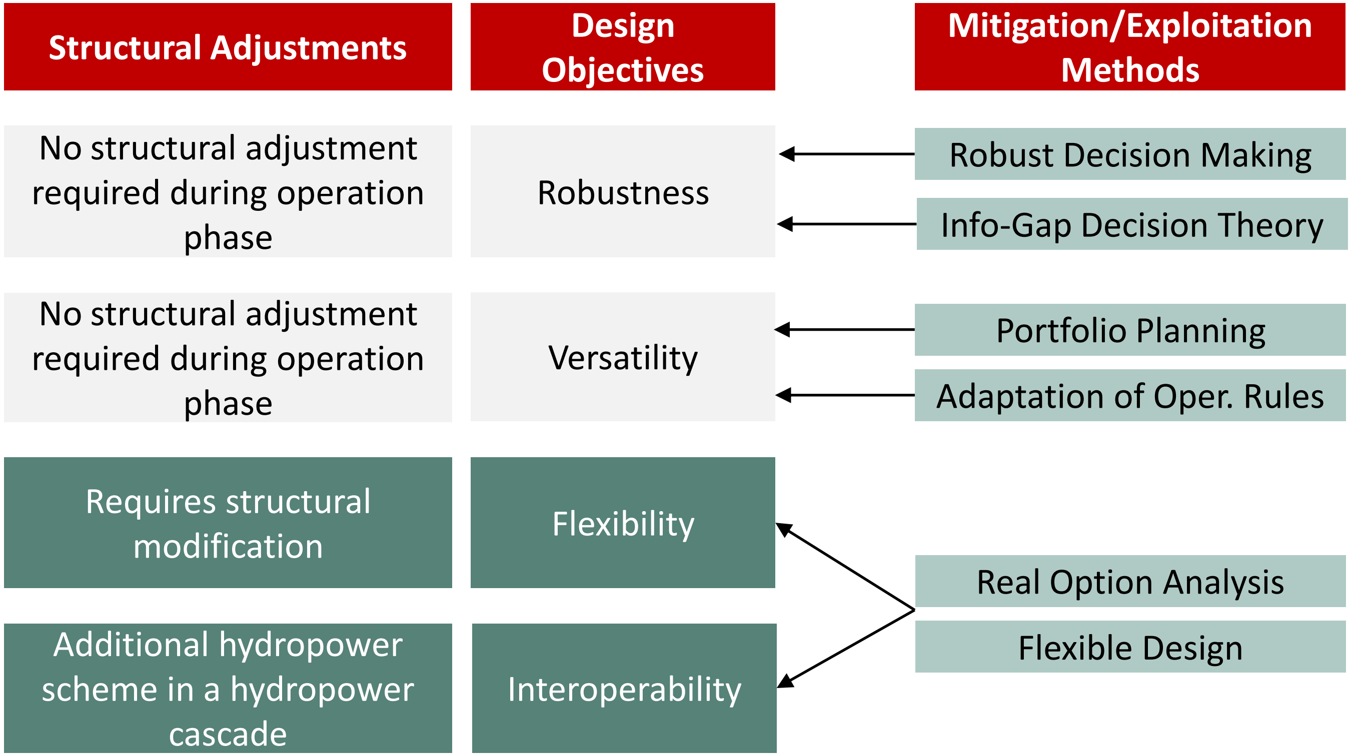
Small HPP suffered a production overestimation
Large HPP had higher production than their targets

Management of Uncertainties

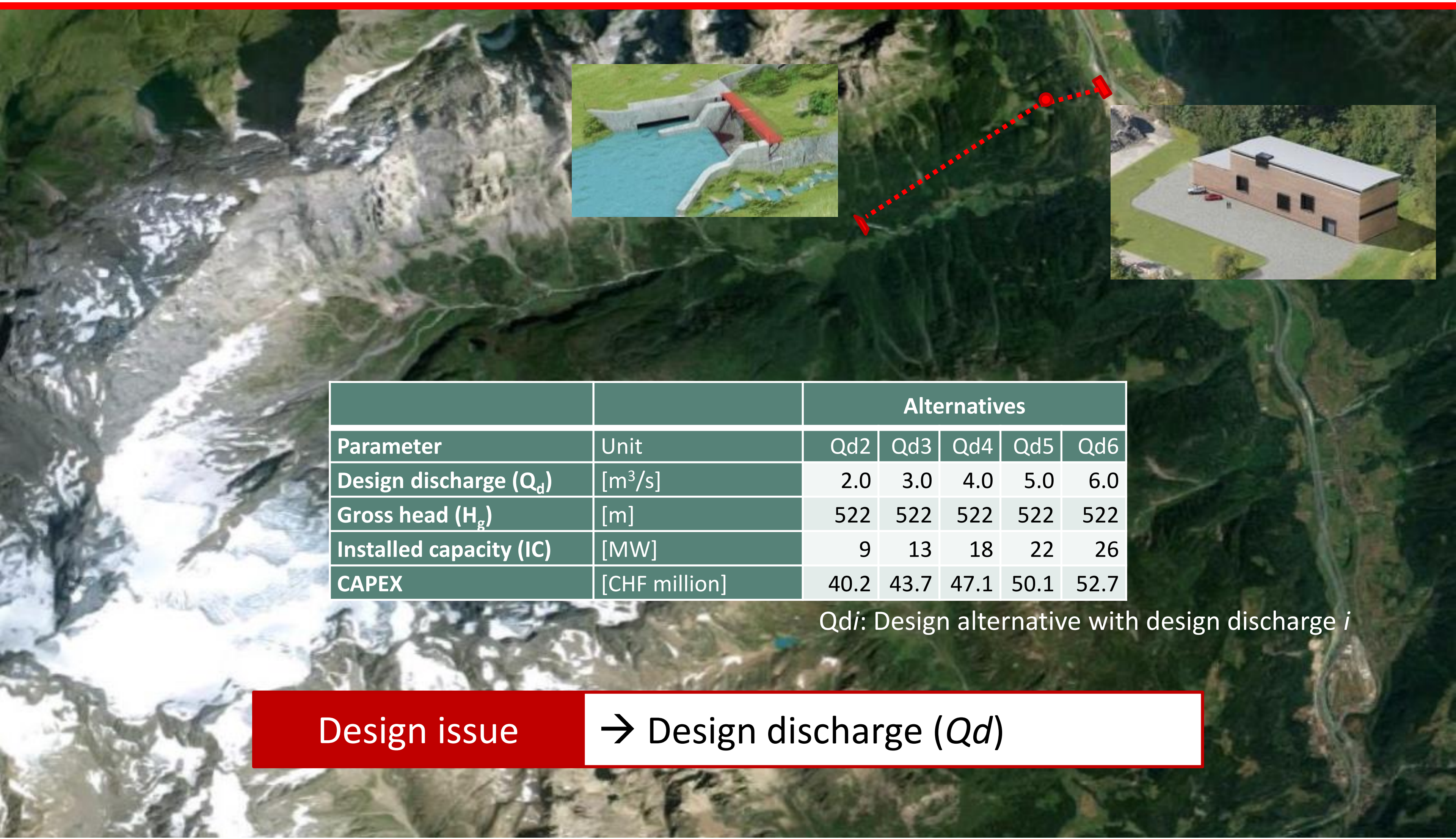
Proposed Framework

Application of New Design Methods

Proposed Framework



Case Study



		Alternatives				
Parameter	Unit	Qd2	Qd3	Qd4	Qd5	Qd6
Design discharge (Q_d)	[m^3/s]	2.0	3.0	4.0	5.0	6.0
Gross head (H_g)	[m]	522	522	522	522	522
Installed capacity (IC)	[MW]	9	13	18	22	26
CAPEX	[CHF million]	40.2	43.7	47.1	50.1	52.7

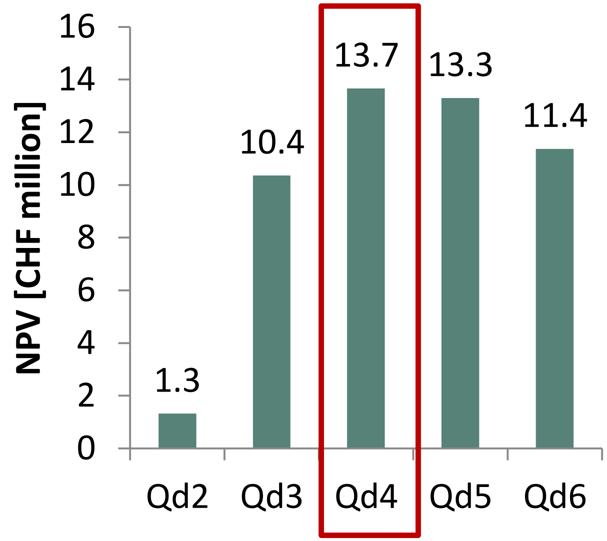
Qd*i*: Design alternative with design discharge *i*

Design issue → Design discharge (*Qd*)

Case Study

Traditional Approach – Optimization

Maximization of NPV



Long-term energy price: 65 CHF/MWh | 30 CHF/MWh - 120 CHF/MWh

Historical inflow (1961-2013): 59.91 million m^3 | up to 71.12 million m^3

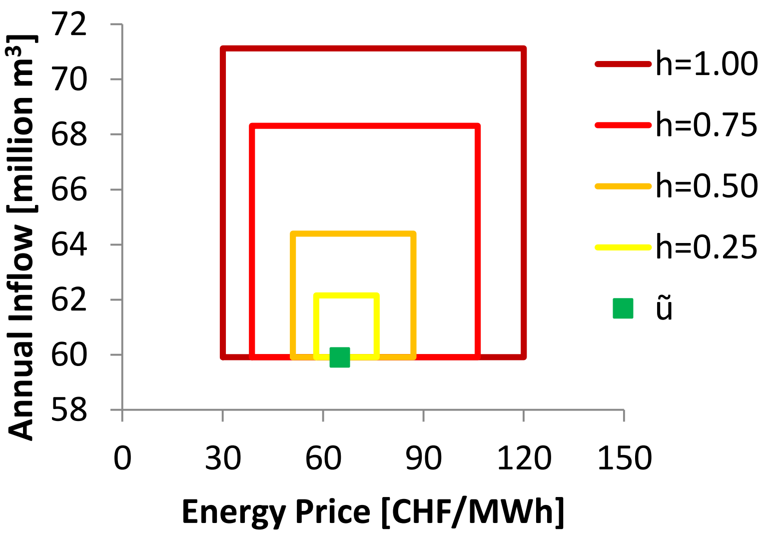
10 Climate change scenarios
(CH2011, 2011; Bosshard et al. 2011)

Robustness-IGDT

- Info-Gap Decision Theory (IGDT)
  - A new approach for hydropower design
  - Theoretical foundation Ben-Haim (2010)
- Uncertainty Model

$$U(h,\tilde{u}) = \{u : max[\sigma_l, (1-\omega_l h)\tilde{u}_i] \leq u_i \leq min[\sigma_r, (1+\omega_r h)\tilde{u}_i]\}$$

	Convention	Value
Estimated energy price	$\tilde{u}_1$	65
Estimated inflow volume	$\tilde{u}_2$	59.91
Lower boundaries	σ_l	σ_l = [30, 59.91]
Upper boundaries	σ_r	σ_r = [120, 71.12]
Scaling factor, left-hand side	ω_l	ω_l = [0.538, 0.000]
Scaling factor, right-hand side	ω_r	ω_r = [0.846, 0.187]



Robustness-IGDT

Performance Requirement

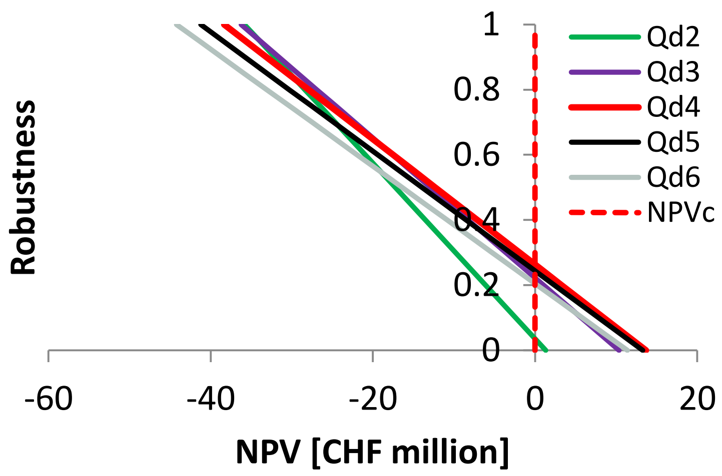
- Outcome to be achieved (NPV_c= 0 CHF)

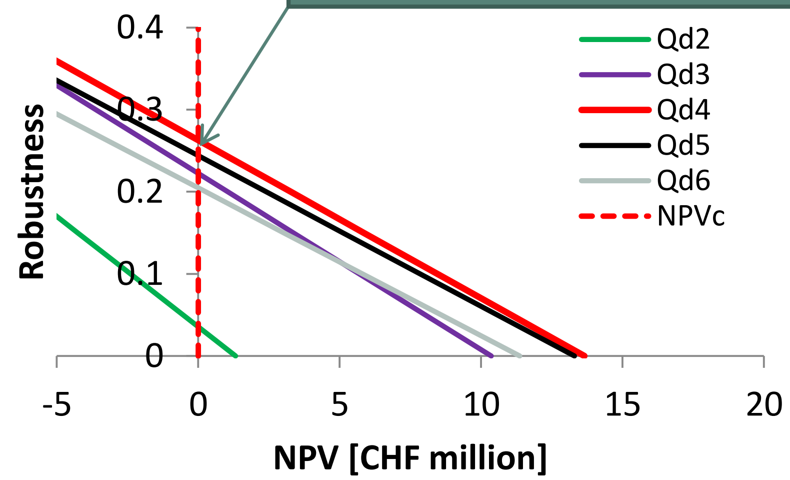
Robustness

- The greatest tolerable horizon of uncertainty by satisfying the performance requirement

$$\hat{h}\,(d) = max\left\{h\colon \min_{u_i \in U(h)} NPV_d\,(u_{1,2}, d) \geq NPV_c\right\}$$

Qd4: Level of robustness 0.26
Decrease of energy price 14%
Historical inflow



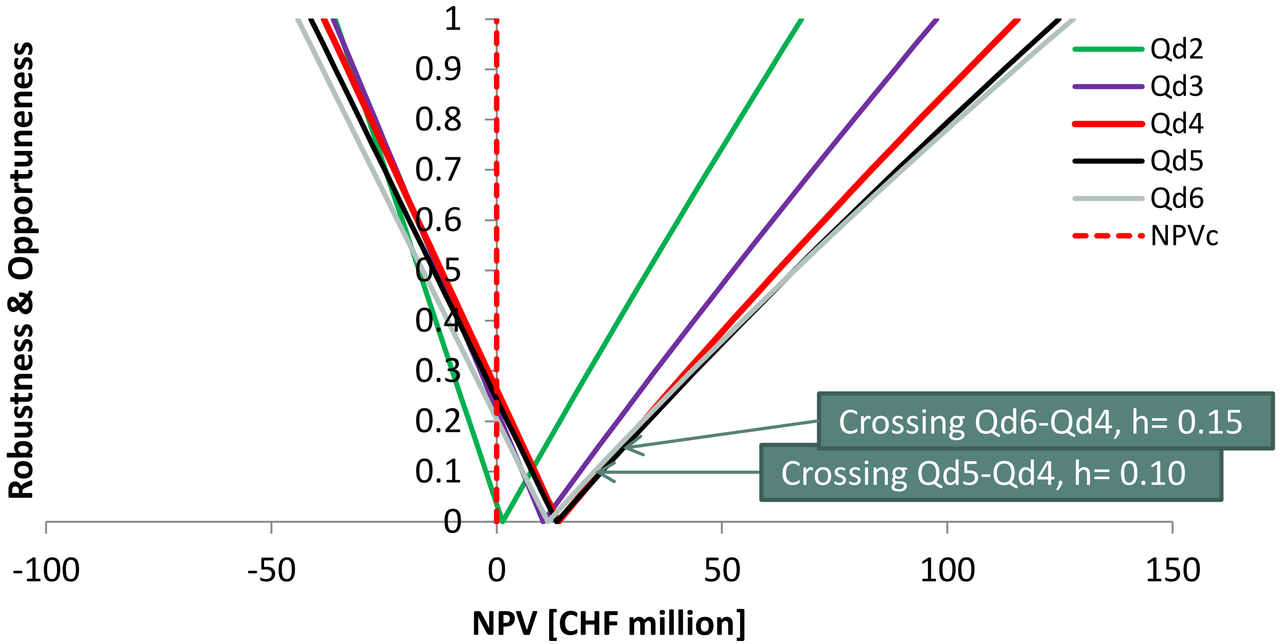


Robustness-IGDT

Opportuneness

- lowest horizon of uncertainty possible for an outcome better than anticipated

$$\hat{\beta}\,(d) = min\left\{h : \max_{u_i \in U(h)} NPV_d\,(u_{1,2}, d)\ \geq NPV_w\right\}$$



Conclusions

Conclusions

1. Uncertainties of Small and Large HPP in Switzerland

Small ←→ Large HPP

- Average cost overruns are similar
- More extreme cost overruns
- Chance to suffer a cost overrun is smaller
- Higher energy production overestimation

« Small is not always beautiful»

2. Management of Uncertainties

- **Framework** for new design methods as guidance for hydropower engineers has been established
- **Promising design methods** were formulated and applied on a **real hydropower** case
- **IGDT as a new approach** for hydropower design has been proved as adequate method

Oberrauch F. 2017: Hydropower Design under Uncertainties. EPFL, Thèse N° 7531

THANK YOU.

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