



SWISS COMPETENCE CENTER for ENERGY RESEARCH SUPPLY of ELECTRICITY

HYDROPOWER DESIGN UNDER UNCERTAINTIES

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Introduction-Motivation

	Corruption	Political uncertainties	s Change of	type of energy	
Political change or instability	Co Fluctuation in market demands	ommercial uncertaint Avai designer, con	ies lability of tractors, suppliers	Change in water charge	ges
Credit ris	sks	Project uncertainties	5 N	larket conditions	
Exchange	Availability of construction materia	Contractor's _I experience	Experience of decision makers	Tendering	
rates Geologica	Ι			Ecological	
conditions	5	Hydropower Desigr	I	impact	
Sedimentation	Selection of gPerformance	lobal design param evaluation	eters • NPV • IRR • LCOE	Design adequacy	
Hydrology	Characteriza	tion of uncertaint	ies affecting HI	Provision of cash flow	
	Design meth	nods incorporating	g uncertainties		
Introduction	Uncertainties Small & Large HPPs	Framework	Application of New Design Methods	Conclusions	2

Structure

1.	Uncertainties of Small and Large HPP in Switzerland	 Analyses of cost overrun and production overestimation
		 Framework of new design methods for

2.	Management of Uncertainties	 Framework of new design methods for hydropower Formulation and application of new design methods on a real hydropower project
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Introduction	Uncertainties Small & Large HPPs	Framework	Application of New Design Methods	Conclusions
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3

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%

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Framework

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%

Uncertainties

Small & Large HPPs

• Larger projects have better performance in energy production forecast



7

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	Large HPP	
	(n= 15)	(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

Introduction Uncertainties Framework Application Design Me	New Conclusions 8
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Management of Uncertainties

Proposed Framework Application of New Design Methods

Structural Adjustments	Design Objectives		Mitigation/Exploitation Methods
No structural adjustment required during operation phase	Robustness	← ←	Robust Decision Making Info-Gap Decision Theory
No structural adjustment required during operation phase	Versatility	←	Portfolio Planning Adaptation of Oper. Rules
Requires structural modification	Flexibility		Real Option Analysis
Additional hydropower scheme in a hydropower cascade	Interoperability		Flexible Design

Introduction Uncert Small & L	ainties Arge HPPs Framework	Application of New Design Methods	Conclusions	10
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Case Study

			Alte	ernativ	ves	
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

 \rightarrow Design discharge (Qd)

Introduction

Uncertainties Small & Large HPPs

Framework

Case Study

Traditional Approach – Optimization

Maximization of NPV

Long-term energy price:



Historical inflow (1961-2013): 59.91 million m³ up to 71.12 million m³

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

ntroduction

Uncertainties Small & Large HPPs

Framework

Robustness-IGDT

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

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



Robustness-IGDT

Performance Requirement

• Outcome to be achieved (NPV_c = 0 CHF)

Robustness

 The greatest tolerable horizon of uncertainty by satisfying the performance requirement



14

Robustness-IGDT

Opportuneness

 lowest horizon of uncertainty possible for an outcome better than anticipated

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



Framework



Conclusions

Uncertainties of Small and Large HPP in Switzerland

Small $\leftarrow \rightarrow$ 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»

 Anagement 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

1.

Uncertainties Small & Large HPPs

Framework

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THANK YOU.

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